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SURVEY

OF

EXPERIMENTAL PHILOSOPHY.

VOL. II.

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A

SURVEY

OF

EXPERIMENTAL PHILOSOPHY,

Conſidered in its

PRESENT STATE OF IMPROVEMENT.

ILLUSTRATED WITH CUTS.

VOL. II.

By OLIVER GOLDSMITH, M. B.

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A SURVEY

A SURVEY OF EXPERIMENTAL PHILOSOPHY.

BOOK II.

CHAPTER I.

Of the Air, and ſome of its Properties.

HAVING juſt calculated the reſiſtance given by the air to bodies in motion, this naturally leads us to conſider the nature and properties of the air itſelf. It was the method with the natural philoſophers that juſt ſucceeded the ages of obſcurity to divide the ſubject of their inveſtigation into as many parts as they ſuppoſed there were elements; namely, earth, air, water, fire. We know nothing of the elements of which bodies are compoſed; but as there is nothing abſurd in the order they have uſed, and as the parts will be more eaſily explained thus, we beg leave to adopt a method, which, though leſs modern, will be found more perſpicuous.

A GREEK philoſopher, when ſome wranglers aſked him for a definition of motion, got up and walked; he ſhewed them the thing, which was the beſt definition he could give. Were we aſked in the ſame manner what is air, we ſhould refer the queriſt to his experience alone for information. Animals breathe the air, birds fly upon it, fire burns in it, ſounds float in it; in ſhort, the beſt definition of this ſubſtance is the enumeration which we are about to give of its properties.

HOWEVER the form of air may eſcape our ſight, yet its ſubſtance ſtrikes all the reſt of our ſenſes; the bladder when filled with air is very different from the ſame when empty, and then reſiſts preſſure with great force. All places on the ſurface of the earth are replete with air, we find it in the bottom of the deepeſt caverns, and upon the tops of the higheſt mountains.

IT was the opinion of Boyle that all bodies whatſoever had an atmoſphere or a thin fluid ſubſtance peculiar to themſelves and floating round them; he ſhewed that the diamond had its atmoſphere, the loadſtone another. The roſe we ſee has an atmoſphere of odorous parts flying round its ſurface, the muſk diffuſes perfume in a very wide atmoſphere, while aſſafætida diffuſes its ſcent into a ſphere equally extenſive. The cæleſtial bodies almoſt all of them that we are ſufficiently near to examine, have their atmoſpheres: when a ſtar is ſometimes hid from us behind a planet, we always find as the ſtar emerges from this temporary eclipſe, that the planet's atmoſphere hides the ſtar for a while longer than we had a right to expect its appearance. As all bodies thus have their atmoſpheres, ſo it is but analogous with the uſual courſe of nature, that the earth alſo ſhould have an atmoſphere or a fluid ſubſtance floating round it filled with particles; and ſome have thought that air is nothing more than earth or water expanded, and aſſuming a more ſubtil form. Theſe therefore compared the atmoſphere to a large chymical furnace; in this the matter of all ſublunary bodies is found floating in great quantities. This great recipient, ſaid they, is continually expoſed to the action of the ſun's heat, from whence reſults a number of chymical operations, ſublimations, ſeparations, compoſitions, digeſtions, fermentations, and putrefactions. This ſect of philoſophers ſuppoſed, and brought experiments to prove, that air could be produced from bodies at pleaſure, that we could make air from earth or plants by a very eaſy proceſs, and that air was in fact nothing but the parts of bodies, which, by being changed, became capable of different properties.

To this purpoſe Boyle has related many experiments by which he made air. By making air he meant drawing it in large quantities from ſeveral bodies that ſeemed unpoſſeſſed of it before, or at leaſt not poſſeſſed of ſuch quantities as were extracted by him from them. He obſerves, that the beſt methods for accompliſhing this are by leaving the bodies to ferment, to putrify, to diſſolve, or in ſhort driving them through any proceſs that will ſerve to diſunite their parts from each other. He adds, that even many minerals, in the parts of which we could expect to meet no ſuch fluid as air, have yet afforded much upon being diſſolved in corroding fluids, ſuch as aqua fortis, which ſeparates the parts of the metal from each other,

other. Hales has made many experiments to the ſame purpoſe. However, after all, we are not to ſuppoſe the air thus made either from vegetables or minerals is the true elaſtic air, the properties of which are now under conſideration.

ALL that appears air to our ſenſes is not really ſo, for we can make even water put on for a time the appearance of air, and yet this water, whoſe nature ſeems thus in a manner changed, will, when left to itſelf for a ſhort time, again reſume its natural form, and look like water as before.

THIS is proved by the very ingenious experiment of the Æolipyle. This inſtrument is a copper globular body, in which is inſerted a ſmall neck or pipe (See Fig. 43.) with a very ſmall orifice, from whence, when filled with water and laid upon the fire, a vapour like wind iſſues out with prodigious violence, and blows like a tempeſt. The way to fill this inſtrument with water is to ſet it firſt while empty upon the fire till it is hot, and then with a pair of tongs it muſt be taken off and the pipe held under water till it be filled as much as you think fit. Thoſe who have not this inſtrument itſelf, may eaſily make one ſomething like it with their tea-kettle, only firſt having filled it with water, and then clapping down the lid very cloſe, ſtopping it round with loam or any ſuch ſubſtance to prevent the ſteam from eſcaping any way but by the ſpout. When this kettle boils, if you hold a candle to the ſpout you will preſently ſee it blown out with ſome violence; and if we could bend down the ſpout in ſuch a manner as to blow againſt the fire, the kettle would blow the fire under itſelf like a pair of bellows. If the water put into the kettle inſtead of being ſimple were perfumed, this would diffuſe the odour with inexpreſſible ſtrength round the room. If a wind inſtrument were properly adapted to this ſpout, it would make it ſound. Such are the effects of water when made to reſemble air, but ſtill it is altogether different from real air; for when this vapour is caught by a proper receiver, it quickly condenſes in drops to the ſides of the veſſel, and no way differs from common water.

IT is exactly the ſame with all other counterfeiting fluids and ſubſtances as with water; how great ſo ever the rarefaction, yet they conſtantly are found after a time to loſe the properties of air, and to aſſume a different appearance. Boyle informs us, that he has drawn an elaſtic fluid from ſeveral bodies, from bread, from grapes, from beer, apples, peas, as alſo from hartſhorn and paper. This ſubſtance had, at the firſt appearance, all the properties of air. But upon examining it more cloſely, it was ſo far from being of the ſame nature with pure air, that the animals which were confined in it, not only loſt all power of breathing in it, but died in it ſooner than in a place from whence he had taken out all the air.

FROM this therefore it appears, that there is ſuch a thing as true air, conſidered as diſtinct from vapours, from factitious air, or any other minute ſubſtance floating in our atmoſphere. It appears that it can neither be converted into other ſubſtances, nor others converted into it. This real air when ſhut up in a glaſs veſſel remains there continually without any change, and always under the form of air. But it is not ſo with vapours, or other rarefied ſubſtances; for as ſoon as they become cold they loſe all their elaſticity, and adhere to the ſides of the glaſs in the form of round drops, while the veſſel which in the beginning ſeemed filled with the vapour, in a manner becomes quite empty.

ANOTHER property by which this pure air differs from vapours is, that by theſe we often hinder our breathing, while, without the other, we could not breathe.

IT differs alſo from terreſtrial exhalations in this, that it remains the ſame after great rains and thunder, as it was before them; whereas, if it was only a compound of exhalations, theſe when fired off in lightning, or falling with rain, would totally deſtroy the compound, and conſequently change the nature of the air; which however is not the caſe, for the air remains unvaried, or, if it receives any change, they leave it more pure.

WE may therefore reſt aſſured, that there is a ſubſtance called air different from all others, and no way allied to them; but then as to the nature of this ſubſtance, the parts of which it is compoſed, the figure of thoſe parts, theſe are things to which we are utterly ſtrangers; all our opinions upon this head are but conjecture. Though reaſon ſerves to aſſure us that this pure air muſt exiſt, yet we have never had the means of examining it ſolely and unmixed with other ſubſtances. Whatever we breathe, whatever we feel, is but an heterogeneous mixture of different bodies floating in this unknown ſupporter; and the different noxious or ſalutary effects aſcribed to air belong properly to thoſe foreign mixtures with which it is impregnated.

BOERHAAVE has ſhewn that the air we breathe is a chaos, or an aſſemblage of all kinds of bodies whatſoever. Whatever fire can divide floats in the air's boſom, and there is no ſubſtance, however hard, that fire is not able at length to ſeparate into fume. Thus, for example, we meet in the air all the ſubſtances which belong to the mineral kingdom, as it is called, ſuch as ſalts, ſulphurs, ſtones, and metals; theſe all by heat can be diſſipated into ſmoak, and conſequently become lighter than the air.

Even gold itſelf, the heavieſt of all minerals, is found in the mine often united with quickſilver; and if we attempt to convert the quickſilver into fumes over the fire, a part of the gold will riſe into the air with it.

IN the air floats alſo all ſubſtances that belong to the animal kingdom. The copious emanations that continually fly from the bodies of all animals, by perſpiration and other means, (thus if an healthy man's arm be put into a glaſs caſe, the perſpiration of the limb will be gathered like a dew upon the ſurface of the glaſs) theſe perſpirations, I ſay, ſend into the air a greater quantity of the animal's ſubſtance in the ſpace of a few months than would make the bulk of the animal itſelf. Even after the animal is dead, if expoſed to the air all its fleſhy parts will ſoon be diſſipated, and in the warmeſt climates, this is often found to obtain in three or four days.

The air is not leſs loaded with vegetable perſpirations. Doctor Hales has calculated that a ſingle ſun-flower perſpires more than a man, but a full-grown tree perſpires in much greater abundance. All theſe perſpirations go to be mixed in the air. When vegetable ſubſtances are left to putrefy, they then become perfectly volatile, and make a part of the terreſtrial atmoſphere.

Thus is our air ſaturated with an infinite variety of ſubſtances foreign to its own nature; but of all the emanations which float in it, Boyle affirms that ſalts are found in greateſt quantity. Some authors think the nitrous ſalts abound moſt in air from the frequency of its being found ſticking againſt old lime-walls, and other ſubſtances, which ſeem fitted for drawing it from the air. This has been denied by ſome of the moderns, who affirm that the nitre is not in the air, but actually in the wall itſelf. However this be, certain it is that the air is im-

impregnated with ſalts of ſome kind or another, and perhaps mixed in a manner perfectly conformable to the chymiſt's art, for their effects in experiment are as powerful as any ſalts he can form. Thus the ſtones of very old buildings are often corroded by the air, and gnawed away in a manner as if it had been done by worms. No unmixed ſalt in the elaboratories of art could do this. From hence we may gather that the bodies which float in air have not only all the properties of which they are poſſeſſed ſingly, but alſo aſſume new qualities which they are often found to poſſeſs by being mixed together. In the chymiſt's elaboratory new and unexpected appearances continually ariſe from the mixture of different ſubſtances together. In the air, the great elaboratory of nature, more different effects are conſtantly produced, for the variety of the ſubſtances which it mixes together is infinitely more.

THE air then ſubjected to ſenſe is a very heterogeneous mixture of various exhalations, but what is the baſe, the fluid that ſupports theſe, we are unable to diſcover. The ancients called it an element, by which they meant one of thoſe ſubſtances of which all others are compoſed. Doctor Hooke calls it Ether, or that ſubtil matter which is diffuſed every where. It has received ſeveral other appellations, but all this is only calling an unknown thing by different names. The ancients were ignorant of its nature, as well as its properties; the moderns are equally ignorant of its nature, but its properties they have inveſtigated with great ſucceſs.

CHAP. II.

Of the moſt obvious Effects of Air upon the Human Body.

EARLY Philoſophy was content with examining Nature as ſhe offered herſelf obviouſly to view. Later enquirers have ſcrutinized more cloſely into her ſecret workings by the means of experiments. Let us firſt then conſider thoſe properties of air which the firſt philoſophers enquired after, and then ſee what wonders modern experiments have ſhewn; and thus following nature upon the view, at laſt purſue her into her more ſecret receſſes.

AIR, as we ſaid already, is the principal inſtrument of nature in all her productions. If we deprive an animal of air by obſtructing the organs by which they inſpire it, the animal will die in a few minutes. If we ſhould by any other means deprive the animal of the free uſe of air by ſhutting it into a cloſe veſſel, the air with which it is thus included would ſoon become unfit for all the purpoſes of life, and the animal would die in a few minutes. Air therefore is neceſſary for the ſupport of all animals; even fiſhes that live in water cannot do without it: if a fiſh is put into a cloſe veſſel of water where the external air is excluded, the fiſh will ſoon die for want of freſh air. The fiſhes in a pond covered over with ice would die if care were not taken to break the ice, and ſo let in freſh air upon the ſurface of the water to fit it for their reſpiration.

WHAT may be the uſes of the air thus inſpired by animals, or why it ſhould be thus neceſſary for the ſupport of life, is a queſtion philoſophers cannot eaſily reſolve. Some are of opinion that there is a ſalt in the air, which the lungs of animals continually imbibe as they draw in their breath. This opinion they gathered from the fine ſcarlet colour of the blood of the arteries juſt as it came from being mixed with the air in the lungs, and that dull colour in the venal blood which it had before. The ſcarlet colour of the blood, they ſaid, reſembled what a ſalt would have given it, while the blackiſh colour of the blood before it came to the lungs, ſhewed that it wanted thoſe ſalts which it afterwards received from the air to fit it for the purpoſe of animal life. This is not true. There is no more ſalt in the ſcarlet arterial blood than in the duſky-coloured venal blood; and in fact, none in either, except a part of that ſalt we eat.

ANOTHER ſect were of opinion that the air was neceſſary to ſupport animal life, becauſe without it the blood could not be driven through the body. For the air, ſaid they, preſſing down upon the large ſurface of the blood in the lungs, like the piſton of a ſyringe drives it through the tubes appointed for its reception, and ſo the blood is driven from one tube to another through the whole body. This is not true: Becauſe the child in his mother's womb has the blood circulating through his whole body, and no air comes to his lungs whatever.

DOCTOR Whytt has given us ſome ingenious conjectures upon this ſubject. He aſcribes much to the irritation of the air upon the internal ſurface of the lungs, which thus contracting to the touch, drives forward the blood through the reſt of the body. After all theſe conjectures, the particular uſes of the air in regulating the animal œconomy, are not yet well known, but even children are convinced of its utility. We rather know what harm it would do us if taken away, than the good it does us being given.

THE air produces ſeveral effects upon the body in proportion as it is charged with vapours and exhalations. This was well known to Hippocrates, and ſeveral ſucceeding phyſicians have given us hiſtories of thoſe diſorders which are produced by the badneſs of air. An air charged with the particles either of arſenic or quickſilver will ſoon become fatal. In the quickſilver mines at Idra I have ſeen the workmen in general miſerably affected from the nature of the atmoſphere in which they were obliged to breathe. The moſt vigorous were in ſome meaſure palſied by working there, and that in a few days; ſcarce any were known to outlive a term of three years conſtant reſidence at the mine.

THE air when filled with exhalations from animal bodies acquires a peſtilential quality, as it is thought, and theſe exhalations have been known to corrupt quickly; the common baths of the warm countries, in which ſeveral bathe in a morning, if not conſtantly changed, would ſoon grow intolerably offenſive. It has been theoretically alledged, that if a number of men were crowded into a ſpace of ſmall extent, the exhalations from their bodies would ſoon form a column of ſeventy-two feet high, which, if not diſſipated by the winds, would become inſtantly fatal to one juſt placed in it. Theory firſt aſſerted this; the number of perſons ſuffocated at Calcutta ſhews the theory to have too true a foundation. From hence we may infer, that thoſe who build or improve cities, ſhould be very attentive to make the ſtreets ſufficiently ſpacious, and not permit their priſons to be crowded with wretches, whoſe numbers muſt neceſſarily breed infection. It were even to be wiſhed, that people abſtained from burying their dead near churches, where there is, or ſhould be the greateſt reſort of the living. Yet, after all, though air that has been too much inſpired by man muſt be unwholeſome, yet probably the air, in ſome meaſure, acquires an healthful quality by being moderately peopled, if I may ſo expreſs it. The air upon a deſolate coaſt, however open and dry the ſoil, is always found dangerous; while univer-

ſally

ſally through Europe the moſt populous cities are reckoned the moſt healthful.

IF braſs or copper plates be heated in the fire, and the vapour that aſcends from them while thus burning be conveyed by blowing or any other means into a cloſe room, animals, in ſuch air, will be inſtantly deſtroyed: this is a very convincing proof how much mines of copper may prejudice the atmoſphere, and deſtroy the wholeſome qualities of the air.

AIR may be heated by a very eaſy experiment; a common pair of bellows, having their end or ſnout heated red hot, will render the air that is blown through it hotter than the hand can bear. Hot air is reckoned extremely prejudicial to health. It has been ſaid, that when air acquired a degree of heat greater than the natural heat of animals, which is uſually reckoned to amount to about an hundred degrees by the moſt common thermometer (as we ſhall ſhortly ſhew) then it was thought the animal could not live in it. However, this is a miſtake; for Mr. Ellis, when in South Carolina, meaſured the warmth of the air, and found it ſeveral degrees greater than animal heat, yet the inhabitants bore its extremity with health and unconcern. However, it will ſtill hold that when the heat of the air is increaſed to many degrees beyond the warmth of the lungs that breathe in it, it will corrupt the ſolids and fluids both, and ſoon bring on death. In a ſugar baker's oven, in which the heat was equal to an hundred and forty-ſix degrees, that is fifty-four beyond animal heat, a ſparrow died in two minutes, and a dog in twenty-eight.

COLD in exceſs has a very injurious effect alſo upon the health of animals, but its malign influence is neither ſo ſudden nor ſo ſure as that of heat. Cold contracts the animal fibres ſo much that the ſame body meaſured in hot weather and then in cold, will be found to be ſhrunk in the latter very conſiderably. Extreme cold acts on the body like ſo many ſmall needles entering its ſurface, at firſt only producing a ſlight itching, then a ſmall degree of inflammation, and ſoon after, if carried to exceſs, a total ſtoppage of the circulation. This irritation of cold is felt peculiarly ſevere upon the ſurface of the lungs internally, where the thin covering of the parts is eaſily affected. The cold air entering into the lungs would be actually inſupportable, but that a part of the warm air, which was left behind in the former expiration, ſtill remains and mixes with the freſh cold air taken in. However, the continual want of perſpiration, the cold cloſing up the pores of the ſkin, together with the continual irritation upon the different parts of the body, in a ſhort time produce the moſt terrible ſymptoms. The ſcurvy is the peculiar diſorder of cold countries, a diſorder which, in the arctic regions, aſſumes very different appearances from thoſe which we are accuſtomed to ſee in this temperate climate; the joints immoveable, an ulcerated body, the teeth falling, old wounds received in the former part of life breaking open again, theſe and ſeveral ſuch terrible ſymptoms are the conſequence of living in an air too cold for the native of a temperate climate to ſuſtain. Such as deſire an hiſtory of the fatal ſymptoms attending this diſorder, may conſult Ellis's voyage to Hudſon's bay, where they will not only ſee the hiſtory of the diſeaſe, but alſo the beſt methods of preventing it.

An air too humid produces a relaxation in the fibres of animals and vegetables. The moiſture inſinuating itſelf through the pores of the body augments its dimenſions. As the ſtring of a fiddle grows thicker and conſequently ſhorter by being moiſtened, ſo do the animal fibres relaxed by too much humidity.

A perſon that ſwims is more wearied by the relaxation of his fibres by the water, than he is by the fatigue of the exerciſe itſelf. This relaxation, if continued to any great degree, ſoon begets a peculiar train of dangerous diſorders; agues, dropſies, and palſies are generally its ſureſt attendants. In ſhort, the air and its peculiar qualities have ſuch an affinity with the human conſtitution, that it ſhould be our care to ſtudy them, if not from reaſons of curioſity, at leaſt from motives of ſelf-preſervation. As humidity is therefore dangerous to the conſtitution, there has been a method contrived of meaſuring the quantity of humidity in the air, that when known we may guard our bodies or chambers againſt it. This cheap inſtrument is called the hygrometer or weather-houſe, which is made merely upon the principle of a piece of cat-gut lengthening in dry weather and contracting in moiſt weather, How bodies thus with moiſture ſwell and ſhorten is eaſily conceived, for the liquid that enlarges the dimenſion of the fibre one way, will neceſſarily ſhorten it the other. If I draw a cat-gut or any other cord to a great length between my fingers, I will make it ſmaller than it was before; on the contrary, when I let it go and when it thus becomes thicker, it becomes alſo ſhorter. To illuſtrate this a little more, for the queſtion is attended with ſome difficulty; and the difficulty is, why the ſame moiſture that enlarges the fibres of the cord croſs-wiſe does not alſo enlarge them length-wiſe? In other words, why, as the cord ſwells, does it not alſo lengthen, for ſuch is the caſe in timber moiſtened in water, as Muſchenbrook juſtly obſerves? This queſtion has been ſolved by different methods. The following will ſuffice. If the cord be ſuppoſed to reſemble an elaſtic tube or gut, and water be forced into it at one end, the fluid preſſing out its ſides equally every way, its dimenſions croſs-wiſe will be encreaſed in a much greater proportion than length-wiſe, and as it is protruded with ſuch exceſs croſs-wiſe, it muſt conſequently grow ſhorter length-wiſe to conform to the forcing power. Such a theory may ſerve for this wonderful appearance of the cord's ſhortening by moiſture; but timber, the fibres of which are more rigid, will not yield ſo readily to the influx of the fluid, and conſequently will not ſhorten in proportion as it ſwells. After all, however, we muſt leave this ſubject in obſcurity, and what is moſt extraordinary, naturaliſts have in general paſſed it over as an object unworthy their notice. The fact, however, is certain; every day's experience ſhews us that cords of all kinds contract with humidity, and lengthen when the weather becomes dry. When Trajan's pillar was a ſecond time reared by Pope Sixtus, we are told that the cords of the machine employed in raiſing it were found too long juſt when the pillar was almoſt upright. The machiniſt that directed the whole was at a loſs, till a countryman taught him to ſhorten the cords by the affuſion of water. However true this ſtory may be, the hygrometer when its cord is ſhortened will mark the humidity of the air, and when the ſame is lengthened it will denote its dryneſs. The uſual method of making an hygrometer is as follows. Let A B C (See Fig. 44.) be the lower part of a twiſted line or cord hanging from the height of the room againſt the wall or wainſcot. On the wall let there be deſcribed a large circle graduated into an hundred equal parts, ſuch as K L M N; in the centre of this circle is fixed a pulley turning upon its axis, and bearing an index or hand upon it O P. If now a cord be put round the pulley, and a ſmall weight or ball ſuſpended at the lower end to keep the cord tight, as the cord gathers moiſture from the air it will become ſhorter, and conſequently turn the pulley upward, and the index riſing with it will point higher as the air is more moiſt. This is an hygrometer that any perſon may make; but an eaſier and ſtill a cheaper I am told may be made by a wild oat-beard, which lengthens with dry weather and contracts with moiſture much more ſenſibly than any other ſubſtance whatſoever. A very ſmall ſhare of ingenuity may form it into a graduated hygrometer, and the ſimpler it is conſtructed the better.

CHAP. III.

Of the moſt obvious Effects of Air upon mineral and vegetable Subſtances.

THE effects of the air, by which I at preſent mean that heterogeneous mixture that floats on our atmoſphere, are ſtill as apparent in the alterations produced on ſome minerals and vegetables as on man. In fact, it is moſt likely that all natural corruptions and alterations proceed from the air alone; for if we keep the air from either minerals or vegetables by any contrivance, either by oiling the ſurfaces of the one, or ſtopping up the others pores cloſe; in ſuch caſes neither will metals ruſt, nor vegetables putrefy. If the air is kept from them, they are ſeen neither to encreaſe or diminiſh, metals ceaſe to change, and vegetables to grow or to corrupt.

THOSE metals which the air can penetrate, ſuch as iron, lead or copper, are ſoon touched, ruſted, and in a number of years are corroded entirely away. On the tops of high mountains, where the air is not ſo much impregnated with foreign materials, things are not ſo apt to change. Words written upon the ſand or the earth in theſe places have been legible forty years after, and appeared no way disfigured or defaced.

BUT though the air, which is a ſubtil fluid, penetrates iron or copper after a ſeries of years, yet in immediate uſe the pores of either give it no admiſſion. The air will paſs through the pores of lead unleſs the metal is firſt hammered upon an anvil. It will not paſs through hard ſtone, nor wax, nor pitch, nor roſin, nor tallow, theſe ſubſtances effectually reſiſt its admiſſion; and if veſſels ſhould be made of theſe ſubſtances, or lined with them, they would keep the incloſed air which was blown or driven into them for ſome years without loſing any part of it. After a long ſeries of years, however, the air will eat its way through theſe ſubſtances, and thus contrive its own eſcape.

THESE keep the air for a long time. There are other ſubſtances which the air will ſoon penetrate. It will inſinuate itſelf through wood, however hard or cloſe it may appear. It will paſs through dry parchment, through dry leather, paper, or a bladder turned inſide out; but if theſe ſubſtances be moiſtened either with water or oil, they then become air-tight: However, if the air be very much rarified, it will not paſs through all ſorts of timber; and if the timber be oiled, it will reſiſt the air better than before. There are but two ſubſtances that reſiſt the air, and confine it without being corroded by it; namely, gold, and vitreous or glaſſy bodies, ſuch as gems of all kinds, and common glaſs.

LET us now therefore ſee what are the effects of air when it thus inſinuates itſelf into the pores of bodies and mixes itſelf with them. We have already ſaid that the air contained a mixture of different ſubſtances, ſalts, metals, ſulphurs, and ſuch-like; theſe when uniting with the ſurfaces of terreſtrial bodies muſt naturally corrode them, as we ſee aqua fortis, which is made of a mineral acid, corrode iron. It is not leſs corroded in the ſpace of a few years by the acid of the air; and the moſt uſual methods of preventing this acid ſalt from entering its ſurface, is either to cloſe up the pores of the ſurface by giving the iron the higheſt poliſh it is capable of bearing, or by oiling it, which will anſwer till the oil is evaporated. Boerhaave aſſures us, that he has ſeen iron bars ſo much corroded by the acid of the air, that he could crumble them between his fingers like duſt. As for copper it is ſoon corroded by the air, and covered with a green ruſt like verdigreaſe, which is no other than the acid of the air mixed with the parts of the metal. As for lead, tin, and ſilver, they all contract a ruſt in like manner. Acoſta informs us, that in Peru the air diſſolves lead entirely; and we ſee our leaden pipes affixed to houſes that have been a long time expoſed, very much injured by the corroſion of the air. Gold is the only metal which we find the air will not ruſt or conſume. The only ſubſtance that conſumes gold is ſea ſalt; this ſalt it is almoſt impoſſible to raiſe into the air, or volatilize, as it is called. It is not wonderful therefore that the air cannot conſume or ruſt gold, ſince it wants the ſalt adapted for this operation; all other ſalts are more eaſily volatilized and made to ſwim in the air, and therefore every other metal finds in the air the ſalt adapted to corrode it. In elaboratories, however, where aqua regia is made, ſea ſalt is volatilized in ſome quantity, and in theſe places gold is actually found to ruſt.

In the operations of the chymiſt many of the changes of bodies are very different, if they be made in a cloſe or an open air. Thus camphire burnt in a cloſe veſſel diſſolves all into ſalts; when, on the contrary, if the ſame proceſs were carried on in the open air, the whole would diſſipate into ſmoak. In the ſame manner, if ſulphur be placed upon an iron plate under a glaſs bell, with the edges cloſe ſtopped, fire being placed beneath, the ſulphur will riſe in ſpirits round the internal ſurface of the bell; but if by the ſmalleſt opening the air within the bell has a communication with the external air, the ſulphur will inſtantly take fire, and the whole will be conſumed. An ounce of charcoal incloſed in a crucible well ſtopped will remain in the fire a whole fortnight without being conſumed or loſing any of its weight; whereas the thouſandth part of the ſame fire applied to it in open air would have conſumed it entirely. Van Helmont adds, that during the whole time the charcoal does not even loſe its blackneſs, but upon the air's being introduced but for a moment, the whole maſs, tho' black before, falls into white aſhes. What befalls the charcoal in this experiment, will likewiſe be the caſe with all other vegetable or animal ſubſtances that are burnt in the fire in a cloſe veſſel and then immediately expoſed to the air.

THE air, when impregnated with the vapours of a mineral, deſtroys all ſubſtances that ſuch a mineral would deſtroy. Thus, in a place where a mineral ore is found in great abundance, the air is impregnated with a vitriolic acid that corrodes whatever it touches. In London, where there is much coal burnt, and where the air is conſequently impregnated with ſulphur, experiments upon ſalts are very different from what they are in an air of a different kind leſs ſulphureous. For this reaſon, the metal utenſils are found not to ruſt ſo ſoon in London as in ſome other parts of the kingdom where wood or turf is the only fire uſed in common. For in theſe latter places the air abounds with corroding ſalts, which, in London, are overcome by the fumes of the ſulphur; and this may be one reaſon among others why that great metropolis is ſo healthy.

THE influence of the air upon ſome ſaline ſubſtances is ſtill more apparent than what we have yet mentioned. Many of them, which, when the air is kept away, continue for a long time under the appearance of cryſtals, upon its admiſſion extract all its humidity, and melt without any other liquid added to them. Some upon the admiſſion of the air change their nature, and from what chymiſts call fixed ſalts become volatile, as, for inſtance, ſalt of tartar, when expoſed to an acid air. On the contrary, volatile ſalts become ſometimes fixed.

IN India, where the nitrous ſalts are found by experience to abound greatly in the air, they dye many colours in much greater perfection than we can in England. In Guinea, the heat, joined with the humidity, cauſe ſuch putrefaction in every vegetable and animal ſubſtance, that the beſt drugs loſe their virtues in that terrible climate. In the iſland of St. Jago belonging to Spain, they are obliged to expoſe their bales by day in the ſun to dry them from the moiſture they have contracted during the night.

WHEN the Dutch, ſaith Boyle, cut down the clove trees of the iſland of Ternati, of which it was full, in order to inhance the price of cloves in Europe, this produced ſuch a change in the air, that the iſland from being extremely healthy, became ſickly and unhealthful to an extreme degree. A phyſician who was then upon the ſpot, aſſured Mr. Boyle that theſe diſorders proceeded from the noxious vapours of a volcano that was upon the iſland, and againſt which, in all probability, the vapours perſpired by the clove tree were an effectual antidote.

THESE and numberleſs ſimilar inſtances might be produced of the power of the atmoſphere over terreſtrial bodies. Whatever chymical diſſolvents can perform, the atmoſphere will be found in time to do the ſame. For the terreſtrial body will attract from the air thoſe ſubſtances with which it has the greateſt affinity; and as ſtraws are attracted by amber, ſo will the acid and vapours of the air by ſubſtances on earth peculiarly adapted to receive them; ſo that the doctrine of attraction is bound to explain all the chymical changes in nature. The very ſeaſons are under its influence; whatever alters the heat of the atmoſphere, as we obſerved above, alters alſo the nature of the air. By this heating property, Boyle ſuppoſes that ſalts and other ſubſtances are kept liquefied in air, and that being melted together they act conjunctly. He ſuppoſes, that by cold they loſe their fluidity and their motion, that they cryſtallize and ſeparate one from the other, and by their weight hang cloſe to the ſurface of the earth, cling to all ſubſtances, and prevent vegetation.

CHAP. IV.

Of Air conſidered as a Fluid.

SUCH are the moſt obvious of that heterogeneous aſſemblage of bodies in our atmoſphere; but that fine and perfectly tranſparent ſubſtance the true natural air which ſupports them, comes next to be taken into conſideration; and its fluidity, or the eaſy yielding of its parts, is one of the moſt obvious of its properties. The eaſe with which it gives way to the ſwifteſt bodies need ſcarce be mentioned; ſounds travel through it with great rapidity, odours and emanations of all kinds find no difficulty in moving forward and preſſing aſide its parts to make way for their own. Theſe all demonſtrate the air to be a moſt yielding ſubſtance which gives way, if not prevented, to every impreſſion; and this is but another name for fluidity. This fluid quality the air never loſes, though it be kept never ſo long in the cloſeſt veſſels, though it be expoſed to the greateſt viciſſitudes of heat or cold, or though it be preſt together with the utmoſt violence of human force aſſiſted by machinery. Still the air continues that yielding fluid it was at firſt; in all theſe caſes it was never found that any of its parts became ſolid, and unbending to the touch, or that they were reduced into any other ſubſtance different from air. Why the parts of this fluid ſtill retain their uſual form we cannot tell; to underſtand this would require a knowledge of the figure of the ſmall parts of air themſelves; to underſtand this, it would be neceſſary to know the dimenſions of thoſe ſmall parts, and alſo to know their mutual tendency to attract or repell each other. None of theſe however are known to us, and therefore the cauſe of the air's fluidity muſt ſtill remain a ſecret; it is ſufficient that we know that it is a fluid, the appearance and not the cauſe is all that we are permitted to underſtand. Carteſius aſcribes its fluidity to an inteſtine motion in its parts. But whence ariſes the inteſtine motion? This motion is even more difficult to be accounted for than fluidity itſelf, a greater wonder is therefore ſuppoſed in order to account for a leſs. Boerhaave aſcribes the fluidity of the air to the heat of the ſun, which keeps it in a ſtate of liquefaction; and he ſuppoſes the whole atmoſphere would congeal into one ſolid maſs if it were not for the aſſiſtance of the ſun's fire. This is contrary to experience; no degree of cold can in the leaſt alter the air's fluidity, or unite its parts into the form of the ſmalleſt ſolid: Beſides, on the tops of the higheſt mountains where the cold is greateſt, the air is (to uſe his own expreſſion) moſt liquefied. Newton's followers have attempted to explain the fluidity of the air by means of their great inſtrument attraction. The parts which conſtitute the maſs of the air, ſay they, may be ſuppoſed to be globular, they therefore touch each other in very ſmall ſurfaces, as all globes muſt. The attraction between two bodies that touch will be leſs in proportion as the ſurfaces that touch, and the quantities of matter in the touching bodies are little. In the parts of air therefore, as both are extremely ſmall, the attraction muſt be alſo very little, and the parts will conſequently be ſeparated from each other with the greateſt eaſe. This hypotheſis, however, ſuppoſes, what, if denied, can never be proved; namely, that the parts of the air are globular; we do not know of what figure the parts of the air conſiſt. However, though we do not certainly know the figure of the parts of the air, it is very poſſible they are ſpherical or globular; firſt, becauſe bodies that are of that figure roll over each other, and give the eaſieſt way to any impreſſion made upon them; and ſecondly, becauſe the larger parts of ſuch fluids as we can view with a microſcope, are of a ſpherical figure. Thus the parts of mercury riſing in fume are all ſpherical, the parts of the blood running through a very ſmall tranſparent vein are ſpherical, ſo is the chyle or that part of our nutriment which is going to be turned into blood. Derham having examined with a microſcope a ray of light paſſing from the ſun into a dark room, found that all the vapours which danced to and fro in this ray were perfectly globular. If therefore all the groſſer fluids are compoſed of ſpherical parts, we may from analogy conclude that more ſubtil fluids are compoſed of the ſame. But notwithſtanding this ſimilitude, we muſt conſider the air as a very different kind of fluid from water, oils, mercury, or ſuch ſubſtances which are called peculiarly liquids. All the parts of liquids we find, when in any quantity, ſunk with a level ſurface; but the air, for aught we know, aſſumes no ſuch ſurface.

BUT though the air differs from other fluids in ſeveral properties, which we ſhall ſhortly ſee, yet it agrees with all fluids in this, that it preſſes in all kinds of directions with equal force; that is, ſuppoſe I ſhould confine air in a bladder, it preſſes againſt all parts of the ſides of the bladder with equal force, and if the air be continued to be driven in, it will burſt that part of the bladder which is weakeſt. That the air preſſes with as much force any one way as another, that it preſſes upward, downward, ſideways, obliquely, in all directions with equal force, may be concluded from an experiment of Mr. Mariotte. He took a long bottle with a ſmall hole towards the middle of its ſide. This bottle being filled with water, the hole being in the mean time cloſed with the finger, a glaſs tube open at both ends was dipped into its mouth, ſo that the lower end of the tube came below the little hole on the ſide. The mouth of the bottle was then well cloſed round the tube with wax, ſo that no air could enter that way. This being done, water was poured into the tube to fill it, and the finger was taken from the hole on the ſide. If with a finger in the mean time the top of the tube were ſtopped, and the ſide hole thus left open, no water would pour through the ſide hole at all for want of vent at top, as the vulgar expreſs it. But both holes being left open at top and ſide, the effects that followed were theſe. The water ran out of the ſide, and deſcended in the tube to below the level of the hole, and the reſt of the bottle remained full. Now from this it appears, that the perpendicular preſſure of the air through the tube is but juſt equal to the lateral preſſure through the hole. For if it exceeded, then the whole of the water would be driven through the hole on the ſide, which however is by no means the caſe, for the air upon the ſide hole preſſes as forcibly as that which comes down the perpendicular opening of the tube, and therefore the air preſſes equally in all directions.

FROM this experiment therefore it appears, that air preſſes in all directions, upwards, downwards, laterally, and obliquely. Now, why ſhould we not conſider the particles of air as thus preſſing in all directions upon each other, and if they preſs each other equally every way, their figures muſt moſt probably be ſpherical. This however is only offered as a conjecture, and luckily for mankind, it matters not whether theſe conjectures be true or falſe.

CHAP. V.

Of the Weight of the Air.

AS light as air, is an expreſſion made uſe of in common converſation, yet it is much heavier than is commonly imagined. We have numberleſs proofs of its weight, many of which though the ancients could eſtimate as well as we, yet they conſidered it as a ſubſtance totally void of gravity, and called it an element. An element was ſomething different from earthly matter, and therefore they conſidered it as wanting material ponderoſity. The uſage of an undefined name thus ſatisfied all their curioſity. However all material ſubſtances, of which air is one, have weight; like other bodies it falls to the earth, and is more denſe as it approaches its center. All people know that air on the tops of high mountains is much rarer and thinner than it is below in the valley; if they ſhould doubt it, the difference they will find in drawing their breath in the different places will clearly convince them. As they go up a very high mountain their breathing becomes quicker, the atmoſphere becomes clearer, neither clouds nor vapours are able to riſe to ſuch heights, and therefore as he aſcends the traveller leaves the tempeſt and the ſtorm midway below him. Ulloa, who went to take the meaſure of a degree upon the Andes in Peru, which are the higheſt mountains in the world, tells us, that when clouds gathered below the mountain's brow while he ſtood on the top, they ſeemed like a tempeſtuous ocean all daſhing and foaming below him, here and there lightnings breaking through the waves, and ſometimes two or three ſuns reflected from its boſom. In the mean time he enjoyed a cloudleſs and ſerene ſky, and left the war of the elements to the unphiloſophical mortals on the plain below him.

SUCH appearances as theſe, with which the ancients were as well acquainted as we, might have led them to conſider the air as having weight; but they were not at this time acquainted with a machine which ſerves to diſcover its weight by proofs much better calculated for conviction than thoſe brought from untried nature. The machine I mean by which we ſo plainly diſcover the weight of the air, is the air-pump. For the firſt invention of this, the world is indebted to Otho Gueric, a German; but it was our countryman Boyle who turned it to real uſes, it was he who improved it, and applied it to philoſophical purpoſes. In the hands of Gueric it was a mechanical inſtrument; in thoſe of Boyle it was a truly philoſophical machine. By this machine we can with eaſe empty a glaſs veſſel of its air, and put what bodies into it we think fit. Thus comparing the changes wrought upon bodies by being kept from air, with the ſame bodies when expoſed to air, we come to a knowledge of the effects of air upon bodies in general.

BUT before we come to examine the uſes of this machine, let us firſt give its deſcription as it is in its preſent ſtate of improvement: rather deſcribing the inſtrument as already made, than giving directions how to make it.

HAVING put a wet leather on the plate L L, (See Fig. 45.) place the large glaſs or veſſel receiver M with its mouth downwards upon the leather, ſo that the hole *i* in the plate may be within the glaſs. Then turning the handle F backward and forward, the air will be pumped out of the receiver by the contrivance of the mechaniſm below, which we are going to deſcribe. As the handle F, repreſented more at large (Fig. 46.) is turned backwards, it raiſes the ſucker or piſton *d e* in the hollow barrel B K by means of the toothed wheel F engraining in the toothed rack D *d:* and as the piſton or ſucker is leathered ſo tight as to fit the barrel exactly, no air can get between this piſton and the barrel, and therefore all the air above *d* in the barrel is lifted up

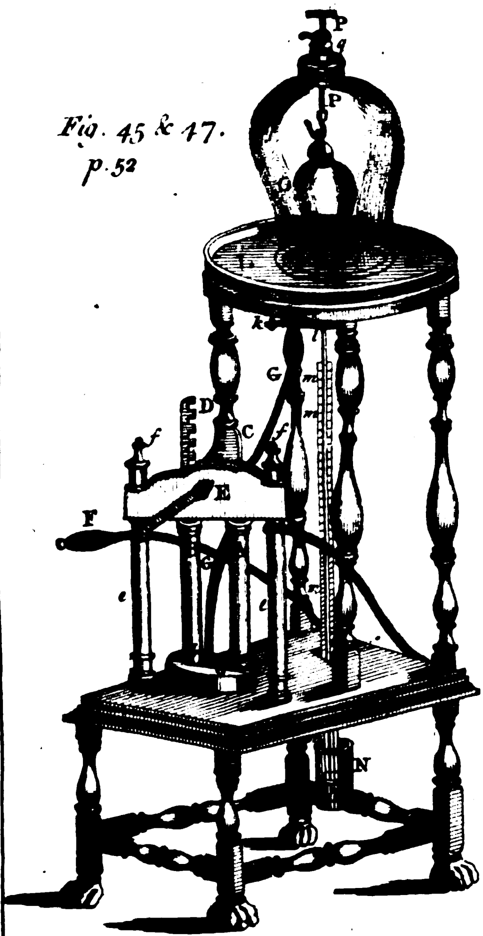
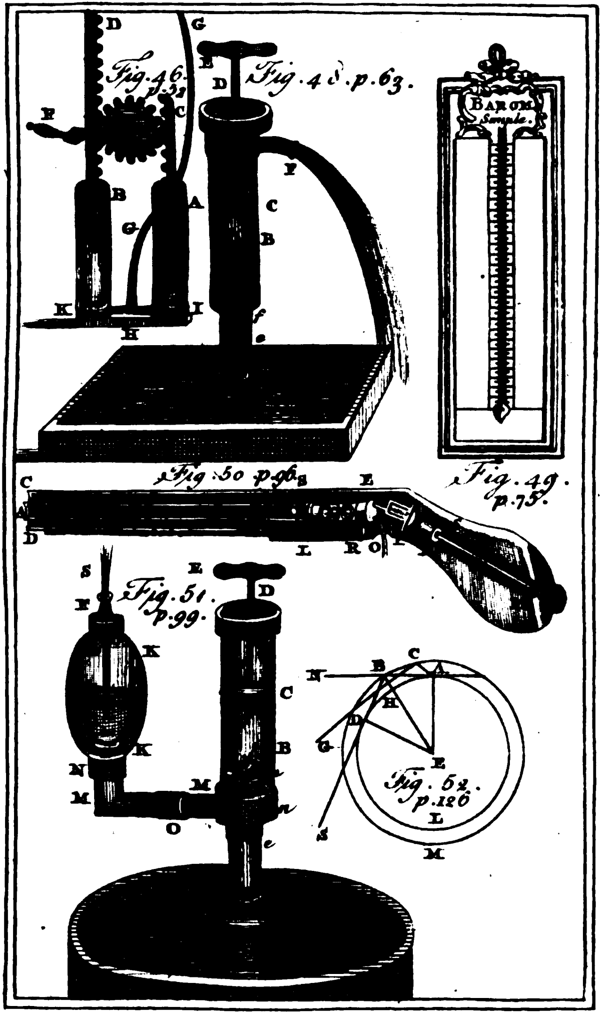


Fig. 45 & 47.
p. 52

Proud sc.

Pl.13 .p.52. Vol.II



Proud sculp.

up towards B, and a vacuum made in the barrel from *e* to *b*: upon which part of the air in the glaſs M (Fig. 47.) by its ſpring ruſhes through the hole *i* in the braſs plate L L along the pipe G G, which communicates with both barrels by the hollow trunk I H K, and puſhing up the valve *b* (a valve is a bit of leather that covers a hole as the flapper of a bellows, admitting the air in, but ſuffering none to go back) puſhing up the valve, I ſay, the air enters into the vacuity *b e* of the barrel B K. For the air will naturally preſs into thoſe places where it is leaſt reſiſted.—All this is done by drawing the handle towards D. Now then turning the handle forward the contrary way towards C, the piſton *d e* is depreſſed in the barrel, and as the air which had got into the barrel cannot be puſhed back through the valve *b*, for the valve cloſes like the flapper of a bellows, and will not let the air back the way it came, the air muſt therefore aſcend through an hole in the piſton, and eſcapes through a valve at *d*; and is hindered by that valve from returning into the barrel when the piſton is again raiſed. At the next raiſing of the piſton, a vacuum is again made in the ſame manner as before, between *b* and *e*, upon which more of the air which was left in the glaſs receiver M gets out thence, and runs into the more empty barrel B K through the valve *b*. The ſame thing is effected with regard to the other barrel A I, and as the handle F is turned backwards and forwards, it alternately raiſes and depreſſes the piſtons in their barrels, always raiſing one while it depreſſes the other. And as there is a vacuum made in each barrel when its piſton is raiſed, every particle of air in the receiver M puſhes out another through the hole *i* and pipe G G into the barrels, until at laſt the air in the glaſs receiver comes to be ſo much rarefied that it can no longer get through the valves, and then no more can be taken out of the receiver. From which it appears there is no ſuch thing as making a perfect vacuum in the receiver; for the air that leaves the receiver is driven out by that which remains behind, there muſt therefore ſome remain behind at laſt.

This is the conſtruction and nature of the celebrated air-pump. Some inſtruments at firſt contrived only for explaining ſcience, become at laſt by frequent uſe a part of the ſcience itſelf, and demand an equal explanation. Such is the caſe with this; and the reader muſt pardon our prolixity in the deſcription. There is a cock *k* below the plate L L, which being turned, lets air into the receiver again. There is a glaſs tube *l m n* open at both ends, and about thirty-four inches long, the upper end communicating with the hole in the pump plate, and the lower end immerſed in quickſilver at *n* in the veſſel N. To this tube is fitted a wooden ruler *m m*, divided into inches and parts of an inch from the bottom at *n*, where it is upon a level with the ſurface of the quickſilver, and continued up to the top, a little below *k*, to thirty or thirty-one inches. Now the quickſilver in this tube riſes as the air is exhauſted in the receiver, for it opens into the receiver through the plate L L. And the more the air is exhauſted, the more will the quickſilver riſe, (for a reaſon we ſhall ſhortly ſee) ſo that by this means the quantity of air pumped out of the receiver may be very exactly meaſured.

BY means of this inſtrument the firſt thing we learn is, that the air is actually heavy. If a veſſel be by means of the air-pump exhauſted of its air, if we clap the palm of our hand to its mouth we ſhall quickly perceive the weight of the air upon the back of the hand, preſſing the hand in a manner into the veſſel. If a part of the ſkin of a bladder ſhould be placed there inſtead of the hand, the external air would break the ſkin with great force, and ruſh into the veſſel with a noiſe. If the air be pumped out of a ſquare glaſs veſſel, the weight of the external air will break the glaſs in pieces. If a flat piece of glaſs be fixed upon the top of an exhauſted receiver, the air without, preſſing upon the flat glaſs, will break it all to pieces. But to put the air's weight paſt all doubt, we can actually weigh it in a balance, and it is there found heavy.

HAVING exhauſted the air out of a thin glaſs flaſk, and ſuſpended it at one end of a balance, which being nicely counterpoized by weights in the other ſcale. This done, admit the air into the flaſk, into which it will ruſh with a noiſe, and though the flaſk was balanced before, it will now upon the admiſſion of the air become heavier and preponderate. If the flaſk holds a quart, it will be found that the weight of the air it now contains is about ſeventeen grains above what it was when quite empty, ſo that a quart of air weighed upon an average in the open air, is about ſeventeen grains.

Now, if a ſingle quart of air weighs ſo much, what would not a pillar of air weigh, the baſe of which reſts upon earth, and whoſe top reaches ſeveral miles above the clouds. The weight of this pillar muſt ſurely be great! The weight of ſuch a pillar, how extraordinary ſoever it may ſeem, can be determined with the niceſt preciſion. We mentioned juſt now with what extreme weight ſuch a pillar reſted upon the back of the hand which had no air under it to keep it up, or balance the weight above it of the air, but we cannot preciſely tell how great that force is as yet. Let us go a little farther then, and ſee with what weight this high pillar of air would preſs upon the ſurface of a tub of quickſilver. Let us ſuppoſe a long glaſs tube exhauſted of all air, and ſtopped cloſe at the top, to be plunged at the other end into it. It is evident that the air will preſs upon the ſurface of the quickſilver without; and if there were air in the tube, it would preſs up the ſurface of the quickſilver within the tube alſo: but there is no air at all, as was ſaid, within the tube, for that was exhauſted before the experiment; ſo that in ſhort all the air will preſs upon the quickſilver on the outſide of the tube, and none upon that within. The air, therefore, as it has great weight, will preſs the external ſurface of the quickſilver all over, and drive it up into the hollow of the tube, where there is no preſſure from air at all. As if I preſſed down the palm of my hand upon water, the water would riſe up between the interſtices of my fingers where the preſſure was leaſt: By means of this preſſure of the heavy air upon the quickſilver, the quickſilver will be driven up into the tube, and riſe in it, if the tube be long enough, about twenty-nine inches and an half high.

THUS then the air preſſes down with a weight capable of making quickſilver riſe to twenty-nine inches and a half. A pillar of air therefore that reaches to the air's greateſt height, is juſt as heavy as a pillar of quickſilver of the ſame diameter that meaſures exactly twenty-nine inches and an half. For the weight of the air preſſing down muſt be juſt exactly equal to the weight of the quickſilver that is preſſed up. When one body raiſes another to its higheſt pitch, and can raiſe it no more, the body raiſed then equals the body raiſing. We may therefore boldly conclude, that a pillar of air which reaches from the top of the atmoſphere, weighs juſt as much as a pillar of quickſilver twenty-nine inches and an half high. The weight of ſuch a pillar we can eaſily eſtimate, and conſequently meaſure the weight of the atmoſphere; but firſt let us mention another caſe ſimilar to this of the quickſilver, which is, water.

If by any means we exhauſt all the air from a veſſel more than thirty-two feet high, and ſtopping one end, ſet the other in water, the water will riſe thirty-two feet within the veſſel and no higher, for the weight of the air will preſs upon the ſurface of the external water as it did before upon the ſurface of the quickſilver, and preſs up the one as well as the other with all its weight. A pillar of water of thirty-two feet high juſt weighs equally with a pillar of quickſilver twenty-nine inches; the air therefore preſſes up that thirty-two feet, as it preſſed up this twenty-nine inches. The weight therefore of a pillar of the atmoſphere is equal to either a pillar of quickſilver twenty-nine inches high, or to a pillar of water thirty-two feet high; it is equal to either, for they are equal to each other.

I ſhall mention an obvious experiment to this purpoſe, which the ſtudent can put into practice without any apparatus while at tea. Some water being poured into a ſaucer, let him burn a bit of paper in a tea-cup, which will drive the air out, and make a vacuum in the cup. Then while the paper is yet burning, let him turn it down paper and all into the ſaucer, and the air without will preſs the water up from the ſaucer into the cup. The water will ſtand within the cup in a column, and if the cup were thirty-two feet high, and the air within it perfectly exhauſted, the water would riſe ſo high in it; as we have ſaid before.

IF what has been ſaid is well underſtood, the ſtudent will be at no loſs to account for the riſing of water in pumps, or the ſtanding of the quickſilver in the barometer.

A PUMP is a machine of ſo much utility, that its conſtruction muſt be deſcribed before we proceed. It is uſed as we all know for raiſing water from deep wells, and thus ſaving the labour of winding it up with buckets, or going down into the well ourſelves to raiſe it. The whole machine is formed upon this principle, that the air will preſs up a column of water thirty-two feet high into a tube or pipe in which there is no air. The air is drawn out of the tube by a piſton or ſucker, and the water follows it. The tube A B I (See Fig. 48.) which we will ſuppoſe is made of glaſs, repreſents the pump, or pump-ſtick, as it is vulgarly called. In this there is a piſton D *d* G, which we can puſh up and down like the handle of a ſyringe, or a churn. This piſton is leathered round at G ſo as to fit the bore exactly, without ſuffering any air to come between it and the tube or pump-ſtick. Now then hold the machine thus conſtructed upright in the veſſel of water K, the water being deep enough to riſe at leaſt as high as from A to L. The valve *a* is fixed within the moveable piſton G, and the valve *b* on the fixed box H, which quite fills the bore of the pipe or barrel at H.

Theſe valves are ſo made as to let all the water come upward, but to ſuffer none of it to paſs downward, for the more the water preſſes back, the cloſer they ſhut. Now then the work begins: by the handle E the piſton which was firſt at B is drawn up to C, and this will make room for the air in the pump below the piſton to dilate itſelf, and therefore it will have leſs weight than the air on the outſide of the pump barrel, and the outſide air will therefore preſs up the water into the tube in proportion to the exceſs of its weight. Therefore at the firſt lift of the piſton the outward air will preſs up the water through the notched foot A, into the lower pipe about as far as *e*. This will contract the rarefied air in the pipe between *e* and C into a ſmaller compaſs, and thus it will become as heavy as it was in the beginning. As its weight or rather ſpring therefore becomes as great as that of the outward air, the outward air can preſs the water at this time no higher than *e*, and the valve *b*, which was raiſed a little by the air's riſing through it, will again fall back and ſtop the hole in the box H, the ſurface of the water ſtanding at *e*. Then the piſton is depreſſed from C to B, and as the air in the part B cannot get back again through the valve *b*, it will, as the piſton deſcends, raiſe the valve *a*, and ſo make its way through the upper part of the barrel *d* into the open air. But upon raiſing the piſton G a ſecond time, the air between it and the water, in the lower pipe at *e*, will be again left at liberty to fill a larger ſpace, and ſo its weight being thus diminiſhed again, the preſſure of the outward air on the water in the veſſel K will force more water up into the lower pipe from *e* to *f*, and when the piſton is at its greateſt height C, the lower valve *b* will fall back, and ſtop the hole in the box H, as before. At the third lifting up of the piſton, the water will riſe through the box H towards B, and then the valve *b*, which was raiſed by it, will fall back when the piſton G is at its greateſt height. Upon depreſſing the piſton the third time, the water cannot be puſhed back through the valve *b*, which keeps cloſe upon the hole whilſt the piſton deſcends. Upon raiſing the piſton the fourth time, the outward preſſure of the air will force the water up through H, where it will raiſe the valve, and follow the piſton to C. Upon the next depreſſion of the piſton, it will force down into the water in the barrel B, and as the water cannot be driven back through the valve *b* now cloſe, it will raiſe the valve *a* in the piſton as this is driven down, and it will alſo be lifted up with the piſton when that is raiſed next; for the valve *a* will not permit it to go back again. And now the whole ſpace below the piſton being full of water, as it is alternately raiſed and depreſſed, the water will riſe through its valve, but cannot deſcend by it; for it cloſes the firmer the more the water puſhes back. Therefore, as the piſton continues to work, freſh water will continually get up through it, and none getting down, it muſt neceſſarily run out at top through the pipe F. And thus, by continuing to raiſe and depreſs the piſton, more water ſtill will be raiſed, which getting over the pipe F into the wide top I, will ſupply the pipe, and make it run with an uninterrupted ſtream. So then at every time the piſton is raiſed, the valve *b* riſes, and the valve *a* falls; and at every time the piſton is depreſſed, the valve *b* falls, and the valve *a* riſes. By this contrivance it is, that water is raiſed in our uſual pumps (for there are other kinds of pumps which we ſhall examine at another time) and if the exhauſted tube in which it riſes be thirty-two feet high, the water will aſcend to that height, and no higher; for the air on the outward ſurface of the water can preſs it down only with a weight equal to a pillar of water thirty-two feet high.

WHAT we have now ſeen with regard to pumps, we may every day ſee practiſed in a ſmaller degree by the common ſyringe. If one of its ends be put into water, and the piſton be drawn up, this will make a ſpace void of air, and the water will be preſſed up into the void, and thus fill the ſyringe.

WHEN children ſuck at the breaſt, it is by a natural mechaniſm ſomewhat reſembling that of the ſyringe; for the child ſwallows the air in his mouth, then ſtops its entrance into the mouth by the noſtrils, and then ſqueezes the nipple between his lips, ſo that no air can come that way. Thus there is a void in the mouth, and the external air preſſing upon the mother's breaſt, ſqueezes the milk into the infant's mouth, and by this means it finds the nouriſhment proper for its ſupport.

CUPPING-GLASSES may be explained upon the ſame principle. That part of the body under the mouth of the glaſs has no preſſure of air upon it; for the air was driven out of the glaſs by heat, before the glaſs was applied. The humours of the body are puſhed to that place where they find leaſt reſiſtance.

ALL theſe appearances in nature are performed, as was ſaid, by the weight of the air preſſing the fluids into places where there was no air, nor any other reſiſtance. But though theſe truths are now as obvious as they are aſtoniſhing, yet for many ages the cauſes of the aſcending of water in pumps was utterly unknown. Philoſophers were content with thinking after Ariſtotle, and his opinion was, that nature hated a void or empty ſpace, and therefore made all poſſible efforts to fill it when the art of man had made one. All this may be very true; but we want to know, why nature hates this void? And here their philoſophy was puzzled. Torricelli was the firſt who undertook to explain, as we have ſeen, why nature made haſte to fill up this void. An accidental experiment put him into the right road towards the diſcovery. Having filled a tube, which was ſtopt at one end, with quickſilver, and then fixed this tube with its open end in a tub filled with the ſame: the quickſilver in the tube did not all deſcend into the tub, but ſtood in the tube at the height of twenty-nine inches and an half. This experiment was ſoon communicated to the learned of Europe: the genius of the times all over Europe was then employed in queſt of new adventures; Boyle, Paſchal, and Riccioli, ſet themſelves to conſider this new phænomenon; and this led them to the following concluſions. Water riſes in a void thirty-two feet high, as we have for ages ſeen in pumps; quickſilver ſtands twenty-nine inches high, as we ſee in this new experiment; a pillar of the one weighs exactly as much as a pillar of the other; the aſcent of both therefore muſt be aſcribed to one and the ſame cauſe. And why may not this cauſe be owing to the preſſure of a pillar of air?

And if the preſſure of this pillar of air were taken away, would the quickſilver then ſtand in the tube? Let the Torricellian tube, veſſel; quickſilver, and all, be placed under the glaſs of the air pump, and let the weight of the air be taken away from the quickſilver. It will then be found to ſtand no longer ſuſpended in the tube, but will ſink down to the ſame level with the reſt of the quickſilver in the veſſel in which it is placed. This was enough, and indeed fully ſufficient to convince them, they purſued the track of light as it led, and at length they deduced a theory of the air equally clear and convincing.

We mortals, who are upon the ſurface of the earth, ſaid they, reſemble fiſhes at the bottom of the ocean: like them we are enveloped in a fluid of air, which riſes far above our heads, an ocean of atmoſphere, which while on earth we cannot quit. This atmoſphere ſurrounds our whole earth for ſome miles high, enveloping the earth on every ſide. Let us ſuppoſe the tops of the higheſt mountains thruſting up their heads through this great fluid, like rocks in the ocean that almoſt riſe to, but not quite ſo high as the ſurface. As the parts of this ambient atmoſphere are all heavy, they preſs down one upon another, and thoſe parts that are loweſt will ſuffer the greateſt preſſure, as they have the greateſt number of parts above preſſing them down. The lower vallies will, therefore, ſuffer greater preſſure from the atmoſphere than the higher mountains. Let then the Torricellian tube be brought into a low valley: here the preſſure upon the quickſilver will be greateſt, and it will riſe above twenty-nine inches and an half. Let it be now brought up to the top of an high mountain: here the preſſure will be leaſt, and it will ſink down proportionably. On the ſummit of Snowdon-hill, Dr. Halley found the barometer above three degrees lower than at the bottom. On the ſummit of an Alpine mountain, the Abbè Nollet found it a quarter leſs high than on the plains of Piedmont. Thus therefore the tube of Torricelli, by the quickſilver riſing or falling, will ſerve very exactly to meaſure the weight of the air.

As the quickſilver in the tube ſometimes in the ſame place ſtands an inch or two higher, and ſometimes ſeveral inches lower, than twenty-nine inches and an half, it is very plain, that the air is ſometimes heavier and ſometimes lighter: that when heavier, it preſſes up the quickſilver above twenty-nine inches; when lighter, the quickſilver ſuffering leſs preſſure riſes not ſo high.

THE tube therefore will exactly determine theſe variations, and its heights will alter with every change. This inſtrument was firſt called the Torricellian Tube; but being now made uſe of for meaſuring the alterations and weight of the air, it is called the Barometer, or

Weather-glaſs. The ſimpleſt and perhaps the beſt method of making the barometer is thus: a glaſs tube, of about thirty-five inches, hermetically ſealed at one end, is to be filled with quickſilver. Hermetically ſealing a glaſs is no more than holding the end in the flame of a candle, or fire, until the glaſs ſoftens, and then twiſting it round, ſo as quite to cloſe up the orifice, and filled with quickſilver well purged of its air, which it may be by boiling the quickſilver in water. The finger being then placed on the open end, this end is ſet into a baſon of the ſame prepared mercury. Then upon removing the finger, the mercury in the baſon will join with that in the tube, and that in the tube will ſink down to about twenty-nine inches and an half, one time with another. Inſtead of a baſon at the bottom, the lower end is uſually turned up, and dilated into a ſort of cup, containing a quantity of quickſilver; upon which the air preſſes, and ſo drives it up along the bend of the tube to the uſual height. This tube thus fitted and filled is then faſtened to a board, which has the inches marked upon it; and towards the top thoſe inches are divided into their parts, in order to meaſure the riſing and falling of the quickſilver more preciſely. (Nollet, fig. 25, vol. II. plate 5.)

It is no eaſy matter to make a barometer which ſhall vary with the minuteſt variations of the weather, for there are ſeveral requiſites which muſt be attended to for this purpoſe. The tube muſt, in the firſt place, be of an equal bore from top to bottom, which few glaſs tubes are found to be. The mercury muſt be perfectly free from air, which it ſeldom is. The tube muſt be no wider in warm weather than in cold, which is impoſſible. Theſe and ſome other inconveniencies have induced artiſts to try other methods of making barometers: they have employed different fluids, ſuch as ſpirit of wine, water, oil, and ſuch like: the ſimple barometer, however, ſeems to be moſt in eſteem ſtill.

AN inſtrument contrived in this manner will pretty nearly ſerve to meaſure the weight of the atmoſphere; it will not preciſely meaſure its weight, becauſe it is affected alſo by another property of the air, namely, its elaſticity or ſpring, as we ſhall ſee in its proper place. By this inſtrument we learn, that the air is changing its weight continually, being ſometimes more heavy, ſometimes more light; but upon an average, its weight (and ſpring together) are able to preſs up a pillar of quickſilver twenty-nine inches and an half high, or a pillar of water thirty-three feet high.

THE atmoſphere thus preſſing down upon the ſurface of the earth envelopes all the bodies upon its ſurface, and preſſes them together. The whole earth may be conſidered to ſuffer as great a preſſure

ſure from the atmoſphere, as if it were preſſed on every ſide by water thirty-three feet deep; and all that are upon the earth's ſurface are as much preſſed on every ſide as we would be, if inſtead of an airy atmoſphere we had an atmoſphere of water, like fiſhes, thirty-three feet above our heads. The weight of ſuch an atmoſphere of water can be eaſily calculated. A cubic foot of water we will ſuppoſe to weigh 60 pounds, 33 feet will weigh 33 times 60, that is 1980 pounds. Suppoſe a middle-ſized man has a ſurface of about 14 feet ſquare, he will ſuſtain 14 times 1980 pounds of water, that is 27,720 pounds. If a man ſuſtains ſo much, who is but 14 feet ſquare, how much weight of atmoſphere will not the whole earth ſuſtain, which hath a ſurface of more than two millions of ſquare miles? The ſtudent with his multiplication table can readily anſwer the queſtion. Thus, whether the earth ſuſtains a weight of water thirty-three feet high, or an airy atmoſphere equal in weight, the difference is nothing, it will be equally preſſed by both. Thus, in the atmoſphere in which we move with ſo much freedom, and which we traverſe with ſo much rapidity, we are preſſed on all ſides with an almoſt incredible weight, and our bodies ſeldom ſupport leſs than twelve ton of air at a time.

So great a preſſure of air upon his body may well ſurpriſe the ignorant, and ſhake his belief; but he muſt conſider, that this weight of air he has carried from his earlieſt infancy. Senſations to which we have been always accuſtomed, are ſcarce felt: we cannot perceive the difference of things, when we have no ſtandard by which to meaſure their variations; we cannot perceive the weight of the air, becauſe we have always felt its weight, and cannot remove from its preſſure. No one part of the body can be diſturbed by its preſſure, for it lays the load equally upon all. Beſides this, there is air within the body, which ſerves to counterbalance that from without; and there is another conſideration alſo, which naturaliſts have paſſed over unnoticed. The heat of our bodies rarifies the air on their ſurface; ſo that in fact an animal doth not ſuſtain ſo great a preſſure from the air as cold inanimate ſubſtances are found to ſuſtain. In ſhort, to uſe the words of Borelli, ſince by the air's preſſure none of the parts of our bodies can ſuffer either ſeparation, or luxation, or contuſion, nor any other change, it is impoſſible that this preſſure can produce any pain.

THIS preſſure then can do no injury to the animal frame, we find it by experience of infinite utility. By it the parts of our bodies are kept compactly together, by it the fluids in our veſſels are prevented from burſting their canals. Travellers, in aſcending high mountains, feel the want of this preſſure, to which they were accuſtomed in the valley: as they aſcend, they perceive a total laſſitude upon them from the dilatation of their veſſels, and at laſt the blood begins to burſt through the fine coats of the lungs, and they ſpit blood. The ſame thing is ſeen in other animals under the glaſs receiver of an air-pump: in proportion as the air is exhauſted, they pant, ſwell, vomit, ſweat, and generally are unable to retain their abdominal contents.

NOR is the preſſure of the atmoſphere leſs ſerviceable in forcing the parts which fly from bodies upon our ſenſe either of taſting or ſmelling. The air in a manner forces them down by preſſure upon the nerves that ſerve thoſe ſenſes: for this reaſon it is, that upon the tops of the higheſt mountains, (the Peak of Teneriff, for inſtance) the ſubſtances which have the ſtrongeſt and moſt pungent taſte, ſuch as pepper, ginger, ſalt, and ſpirit of wine, are there almoſt inſipid: there perfumes loſe their odour, and aſſafœtida its ſcent. This ariſes from the want of a ſufficient agent to impreſs the ſmall parts of thoſe bodies, that are continually flying off, either upon the olfactory nerves, or on thoſe of the tongue.

The preſſure of the atmoſphere is alſo equally ſerviceable to the vegetable world. By it the juices in the tubular parts of vegetables are prevented from burſting their channels, and a proper quantity of air is preſſed into them, and thus ſerves to carry on that continual flow of ſap through all their parts, by which means they vegetate. If this preſſure is taken away, plants no longer vegetate: the moſt thriving flower, when conveyed under an air-pump, quickly withers and fades, the air within expanding eſcapes through the pores of the plant, and leaves its juices deprived of the agent that helps to drive them forward.

In the inorganized parts of nature this preſſure too is entirely neceſſary; for it is owing to this preſſure that many bodies mix with each other, which they would not do in a void. Thus liquids, ſuch as oils and ſalts, which mix readily of themſelves in the open air, will not, when placed in an air pump, unite with all the art of man. In conſequence alſo of this preſſure, and of the air's fluidity, it is that the action of fire is directed from one body upon another, and becomes efficacious. Thus fire in the open air may be applied to wood, and the fire will effectually burn it; but when the ſame is applied in the exhauſted air-pump, the flame will no longer operate upon the wood, for there is then no longer an agent which can preſs its parts upon the ſubſtance which it is ſet to conſume. The ſame thing will happen if we attempt to diſſolve gold in aqua regia. This menſtruum ceaſes to act upon the metal as ſoon as the air is pumped away. This property of weight in the air alſo produces the winds, as we ſhall be led ſhortly to believe. In ſhort, the weight of the atmoſphere, inſtead of being injurious, is our greateſt comforter and aſſiſtant: when it is heavieſt, our ſpirits are found to be lighteſt; when by preſſing down it drives up the quickſilver in the weather-glaſs to its greateſt height, it is then we feel ourſelves invigorated and enlivened. The weather-glaſs ſhews us, that in fine weather the atmoſphere is then always the moſt heavy; and yet there are few who do not find themſelves on ſuch occaſions more alert than in dull weather, when the ſmall preſſure the quickſilver ſuſtains evinces that the atmoſphere is then moſt light.

CHAP. VI.

Of the Elaſticity or Spring of the Air.

IN the laſt chapter we only made mention of the weight of the air, and of the effects of its preſſure; but this preſſure is increaſed by another cauſe, I mean the air's ſpring or elaſticity. We explained ſeveral appearances in nature that reſulted from its preſſure; but theſe appearances were not entirely cauſed by preſſure alone, for the air's elaſticity conſpired with its weight to work theſe effects: by the aſſiſtance of this property, water riſes in pumps, and ſtands in the barometer.

BY the elaſticity of the air is meant that property, which this fluid has peculiar only to itſelf, of yielding to preſſure on every ſide, and then upon the preſſure's being taken away, ſpringing out to its former dimenſions. Water, which is a fluid, can ſcarcely be preſſed into a ſmaller compaſs by all the art of man; nor can quickſilver be compreſſed: ſteam, which is a fluid, may be compreſſed into a ſmaller ſpace, indeed; but then we deſtroy its properties: it turns to water, and therefore cannot recover its former dimenſions. Air is the only fluid we know that can be preſſed into a ſmaller ſpace than that in which it was contained before, and which, when the force is removed, recovers its former dimenſions. Thus the air, for inſtance, which fills a bladder, might be preſſed into the ſpace of a nut-ſhell. And as the air may be thus compreſſed into a ſmaller ſpace, ſo it can be dilated to fill a larger: the air that fills a bladder, if ſuffered to expand, would diffuſe itſelf equally, and fill a whole houſe.

INFINITE are the proofs which may be brought to prove this elaſtic ſpring in the air. A bladder, when blown, may be preſſed in by the finger; but the air, upon the removal of the preſſure, with true elaſtic force puſhes the part out again. If we place this bladder, almoſt quite empty, in the receiver of the air-pump, and then exhauſt the air from the receiver, the air within the bladder will then exert its power of dilating, the preſſure of the external air being taken off, and the bladder, before flaccid, will now appear full, as if juſt blown up by the breath. A flaccid bladder, carried up to the top of a mountain, will exhibit the ſame appearance; the air without being more thin at that height, the air within will dilate itſelf. If inſtead of putting an half-empty bladder under the air-pump, we ſhould put a blown bladder there, when the void is made around it, the force of the ſpring of its internal air is too ſtrong for the ſides, and the bladder quickly burſts. If, inſtead of a bladder, we ſhould try the experiment upon glaſs bubbles filled with air, the effects would be the ſame: theſe, like the bladder, would burſt in pieces.

THIS ſhews the air to be elaſtic; but it alſo ſhews, that this elaſticity is very different from the elaſticity of an ivory ball, or a coiled watch-ſpring, or any ſuch ſubſtance, to which the air has been ſometimes compared. An ivory ball, when the preſſure, which bent its parts inwards, is removed, ſtarts out again to its former ſize and ſhape: a watch ſpring, when the preſſure that keeps it coiled is removed, flies out to its former length. But it is very different with a bladder of air: if the preſſure is removed from its ſurface, the air contained not only ſtarts out to fill the ſame ſpace it occupied before, but ten thouſand times that ſpace, if no new preſſure prevents it from dilating.

TO account for this ſurpriſing force of expanſion, of which the air is poſſeſſed, has not a little employed the thoughts of the ſpeculative. Some have compared the air to watch ſprings or hoops, which coiled up by preſſure, reſtore themſelves again. Others reſembled the air to little flocks of wool: No more, ſaid they, is neceſſary, if we would produce elaſtic air, but to ſeek it in bodies thus diſpoſed in ſpiral circles; and bodies, which are moſt ſuſceptible of this elaſtic diſpoſition, are ſuch as will moſt eaſily furniſh air. And for that reaſon it is, continue they, that liquids cannot be converted into air, becauſe of the roundneſs and ſmoothneſs of their parts.

ALL this, which is obſcure enough, has been juſtly controverted by Newton. The air's extreme expanſion to a ſpace an hundred thouſand times greater than what it poſſeſſed upon preſſure, could not be accounted for upon ſuch a bungling mechaniſm as that of a watch ſpring, which cannot expand a thouſandth part of what we find the air to do. He therefore thinks, that as all bodies have a repulſive power as well as an attractive, this repulſive power always begins to act when the attractive power can reach no farther. Now the parts of the air, which he ſuppoſes to have been ſolid at firſt, and which were conſequently while ſolid within the ſphere of each other's attraction, being in this caſe driven aſunder by ſome external interpoſition, ſuch as fire, or any other agent, no matter what; theſe parts thus ſeparated loſe their attractive and acquire a repulſive force. The parts fly from each other, expand, and fill a ſphere almoſt equal to the extent of imagination: for, to uſe his own words, "Particles (ſays he) "when ſhaken off from bodies by heat "or fermentation, ſo ſoon as they are "beyond the reach of the attraction of "the body, recede from it, and alſo from "one another, with great ſtrength, and "keep at a diſtance, ſo as ſometimes to "take up a million times more ſpace than "they did before in the form of a denſe "body." This vaſt contraction and expanſion ſeem unintelligible, by feigning the particles of air to be ſpringy and ramous, or rolled up like hoops, or by *(feigning)* any other means *than that* of a repulſive power.

As we thus ſee the particles of air, when the external preſſure is removed, fly from each other with ſuch repulſive force, it will be matter of curioſity, and of moment alſo, to inquire how great that force is, and how much it is diminiſhed, as the particles of air are leſs preſſed together. In the firſt place, then, Boyle and Mariotte have found by experiment, that the leſs forcibly they preſſed the particles of air together, the leſs violently did the particles of air repel each other; and ſo, on the contrary, the more violently they preſſed a body of air, the more forcibly did the air reſiſt their preſſure, the repelling power of its particles becoming greater the nearer they were driven to each other. Thus, for inſtance, ſuppoſe a gallon of common air were to be preſſed into a ſmaller compaſs, if a preſſure of one hundred pound ſqueezed this air into a pottle, it would require the preſſure of two hundred pounds to ſqueeze it into a quart, the preſſure of four hundred pounds to ſqueeze it into a pint, and ſo on. But another experiment will lead us ſtill farther, and ſhew, that the force with which it expands is always equal to the force which preſſes it. Let us ſuppoſe an upright tube thirty inches long, its lower end plunged into a bottle half filled with quickſilver, the mouth of the bottle cloſed faſt round it, and the tube open at top. Let us next imagine a glaſs receiver, by ſome contrivance made tall enough to cover this tube, bottle and all, and let the receiver be then exhauſted of all its air. The air in the inſide bottle, however, cannot be exhauſted, for it cannot eſcape; the mouth is cloſed faſt round the tube, and therefore it muſt preſs upon the quickſilver beneath. This it will do, and puſh it into the tube, whoſe end was plunged into it, and the air, ſtill continuing to preſs the quickſilver, will at length preſs it, merely by its ſpring or elaſticity, as high as it would actually riſe in the barometer, by the weight of a pillar of air reaching to the top of the atmoſphere. The air's elaſticity, therefore, muſt be equal to the weight; and whatever be the weight or preſſure upon any part of the air, its elaſticity muſt be equal to it.

FROM hence then we ſee, that whatever effects are wrought by the weight of the atmoſphere in preſſing up quickſilver into the barometer, or into pumps, the ſpring or elaſticity of the air is able to perform the ſame. Yet we are not for this reaſon to diſcard the weight of the atmoſphere, and conſider it as no way neceſſary in producing theſe effects: an opinion ſome have actually embraced. By no means: it is the weight of the air that gives it its great elaſticity; take away the weight, and the elaſtic force ceaſes. On the tops of mountains, where this weight is leſs, the air is leſs elaſtic alſo, and it preſſes up quickſilver above three inches ſhort of what it is found to do in the valley.

Boyle was of opinion, that the air, at the ſurface of the earth, was preſſed into almoſt fourteen thouſand times as much leſs ſpace as it would dilate to by virtue of its own elaſticity.

Many authors have taken pains to calculate into how wide a ſphere its particles would diffuſe themſelves, if ſuffered to expand at freedom. This inquiry is ſubject to many difficulties; for to know how much the air would dilate itſelf, we muſt conſider it as purged from thoſe heterogeneous mixtures, with which we ever find it united. Muſchenbroek, from ſome inconcluſive experiments, ſuppoſes that the air at the ſurface of our globe might be dilated ſo much, as to fill a ſpace four thouſand times as large as that it at preſent uſually occupies. Boyle, as I ſaid, affirms, that by means of the air-pump he has rarefied common air ſo as to fill near fourteen thouſand times the ſpace which it occupied before; but air condenſed into its ſmalleſt ſpace could fill 50,000 times as much ſpace as it did before. In ſhort, ſo great is this rarefaction, which can be produced by art, that ſome have ſuppoſed, that if a nut-ſhell filled with air were ſuffered to dilate, it would fill all ſpace. This, however, is but mere ſpeculation.

WHETHER air can be infinitely dilated or not, we cannot tell; and wherever the doctrines of infinity enter into philoſophy, knowledge ceaſes, and we talk at random. This however is certain, that air can be found deprived of its expanſive elaſtic force, and therefore we may readily conceive a point, to which, if it dilates, it ceaſes to be elaſtic. Hawkſbee has ſhewn us, that its parts can be ſo diſcompoſed by violent preſſure, that it cannot recover its tone till after ſome time, and this only by preſſing it into water,

ter, and then obſerving how much time it took to diſengage itſelf. Fontenelle aſſures us, that humidity in ſome meaſure deſtroys the elaſticity of the air for a time; but though the teſtimony of theſe naturaliſts may be controverted, yet that of Hales muſt confirm us in the opinion: for he deprived the air of its elaſticity by the fumes of ſulphur, and perhaps there are many natural exhalations which produce the ſame effect, and therefore, when the air arrives at a certain height, it may ceaſe to expand, and ſo terminate the ſurface of our atmoſphere.

As the air is thus capable of the moſt elaſtic expanſion, ſo is it alſo of being preſſed into a ſmall compaſs. How far this preſſure may reach, or what is the ſmalleſt poſſible degree to which a certain quantity of air may be reduced, has not yet been well aſcertained. Halley aſſures us, from his own experiments, and thoſe of the academy of Cimento, that the air may be reduced into a ſpace eight hundred times leſs than what it poſſeſſed before in common. Halley, however, has gone much farther than this: by means of freezing it, when mixed with water in an iron ball, he reduced the air into a volume eighteen hundred times leſs than it had before: ſo that we ſee by this means air was condenſed into a ſubſtance twice as heavy as water, a thing which may excite ſurpriſe. Upon this ſuſceptibility of condenſation in the air, and its ſurpriſing power of expanſion, when preſſure is removed, has the air-gun been contrived: an inſtrument by which balls are ſhot off with the force even of a cannon, by the ſpring of the air only, and which, without making any report, carry the moſt ſure deſtruction. The common air-gun is made of braſs, and has two barrels. The middle barrel KA (ſee fig. 50.) from which the bullets are ſhot, and the larger outſide barrel, cloſed up at the end CD, and in this the air is driven and kept condenſed, by means of a ſyringe M, which drives the air in, but ſuffers none to go back. This ſyringe having been worked for ſome time, the air is accumulated in great quantities in the external barrel, and this air may be made to ſtrike upon the ball K by means of the trigger O, which pulls back the ſpiral R, and this ſpiral opens a valve behind the ball. When the valve is open, the air condenſed in the outward barrel ruſhes in behind the ball, and drives it out with great violence, ſo great, that at twenty-ſix yards diſtance it would drive through an oak board half an inch thick. If the valve behind K be ſhut ſuddenly, one charge of condenſed air may make ſeveral diſcharges of bullets. The little pellet guns in the hands of children ſhew alſo the force and ſpring of the air; for one pellet ſtopping the mouth of the gun at one end, and another being driven in at the oppoſite end, the air contained in the bore of the gun between each pellet is continually condenſing, as the hinder pellet is driven towards the foremoſt, till at laſt the ſpring becomes ſo great as to drive the foremoſt pellet forward with ſome noiſe and violence. In the large air-gun, however, the noiſe is by no means ſo great: upon its diſcharge nothing is heard but a ſort of a ruſhing wind; and it is very poſſible, that what we are vulgarly told of ſome men killing others by loading their piſtols with dumb powder, might have proceeded from the ſilent effects of the air-gun.

THIS, however, is but an inſtrument of curioſity, and ſometimes of miſchief; but upon the expanſive ſpring of the air it is that the fire-engine has been formed, a machine of the utmoſt benefit to mankind in one of the moſt terrible ſituations. This is uſed for extinguiſhing fires; for by means of the ſpring of the air, which is condenſed within the machine, the water is ſpurted out through a pipe to an height above the top of an ordinary houſe;

for water, as we ſhall ſee, can be forced in a continued ſtream not much higher, its parts ſeparating, and the whole dividing into the ſmalleſt drops. That the mechaniſm of the fire-engine, or Newſham's engine, for he was the inventor, may be underſtood, we muſt have recourſe to the machine in its ſimpleſt ſtate, namely, the forcing pump, as it is called. Let us ſuppoſe a common water-pump, ſuch as we have already deſcribed, DA (ſee fig. 51.) raiſing its water through the box H, upon lifting up the piſton D. But the piſton of the forcing pump differs from that of the common pump, in having no hole through it at *d*, as the other has: ſo that it will not permit the water in the barrel BC by any means to get above it when it is depreſſed to B. Therefore the water between the piſton *g* and the box H can get neither up nor down, neither through the piſton as it is not perforated, nor back through the box H, for the valve there cloſes againſt it;

but it has a free paſſage ſideways by the hole *mn* into the pipe MM, and this way it goes till it aſcends into the air veſſel KK, up through the pipe at L, As it enters at P, there is a valve *a*, which permits it readily to enter, but never ſuffers any to get back. The water then being thus forced into the air veſſel KK, by repeated ſtrokes of the piſton, it riſes above the lower end of the pipe GHI, and then begins to preſs the air in the veſſel KK into a narrower compaſs, and thus condenſing it encreaſes its ſpring. For the air has no way to get out of this veſſel, the only opening it had was through the hole I at the bottom of the tube, and this is now covered up with water. The air therefore is more and more preſſed, the more water is forced into the air veſſel, till at length it begins to exert its ſpring againſt the ſurface of the water at H. This ſpring therefore forces up the water through the pipe IHGF, from whence it ſpouts in a jet S to a great height; and this may be continued as long as we chuſe to work the machine, and there is any water to ſupply it. This inſtrument was in uſe in miniature as a thing of mere curioſity among naturaliſts, till the above ingenious and intelligent machiniſt converted it to the moſt uſeful purpoſes. If we ſhould deſire to know, how the water may be driven in one of theſe inſtruments, it is obvious, that the more the air in the veſſel KK is preſſed, the more forcibly will it be driven through the pipe F. If the compreſſion be equal to double the weight of the atmoſphere, the ſpout will be thirty-three feet high; if the compreſſion be three times greater than the weight of the atmoſphere, the ſpout will be (all circumſtances the ſame) ſixty-ſix feet high; if four times, then ninety-nine feet high, and ſo on. Thus, by encreaſing the compreſſion, the water will ſpout higher, and this compreſſion will be encreaſed only by leſſening the hole, by which the water is to eſcape from its force, or, in other words, by diminiſhing the diameter of the tube. But of this elſewhere.

THUS powerful is the expanſive force of the air; but ſtill more powerful would it be if, by means of fire, we encreaſed the elaſticity of its parts, or their aptitude to ſeparate. It is an incontеſted truth, that heat will expand air to a moſt ſurpriſing degree. Indeed, heat ſerves to expand all bodies whatſoever, but by no means in ſuch great proportion as it does air. How heat comes to have this extraordinary power upon air we cannot tell: the cauſes of many things we are ſtrangers to, and muſt be contented with knowing the phænomena. Heat expands the air in an amazing degree, and cold, on the contrary, condenſes and contracts it. If, in proof of this, I hold a bladder half blown near the fire, the heat will ſoon encreaſe the elaſticity of the internal air, the bladder will ſwell, and at laſt burſt. If I place a glaſs bubble filled with air in the fire, when the contents begin to rarefy with heat; the bubble will burſt with a loud exploſion. So great is this expanſion cauſed in the air by heat, that ſome have been of opinion, that the air owed its expanſive force only to the heat it contained; and as was ſaid in a former chapter, if the air were deprived of all heat, it would quickly be condenſed into a ſolid maſs. However this be, Amontons has found, that the heat of boiling water encreaſed the force of air at leaſt a third part greater than it was before. And he alſo has proved, that the more denſe the air is, the more will an equal degree of heat expand it. If, for inſtance, a quart of air be condenſed into a pint, an heat equal to that of boiling water will operate twice more powerfully upon the compreſſed pint, than upon the quart that is twice leſs compreſſed. Thus we ſee with what force a ſmall quantity of air may be made to preſs upon the ſurface of the earth, its weight from the height of the atmoſphere, its elaſticity which is equal to that weight, and the encreaſed elaſticity which it may receive from being heated. A ſmall quantity of air acting with theſe three forces conjointly, might be able to cauſe an earthquake; but whether air thus expanding be actually the cauſe of earthquakes, we cannot determine: it is probable that it is not; but very poſſible that it might be.

How great the power of the air is, though only acting with two of theſe forces, namely, its natural elaſticity, and that which it acquires by heat, may be ſeen in the experiment of a cloſe veſſel, which has received the name of Papin's Digeſter. The effects of this digeſter are perhaps ſome of the moſt ſurpriſing that experimental philoſophy is capable of exhibiting. The digeſter is nothing more than an iron veſſel of moderate thickneſs: into this is put meat, bone, hartſhorn, or any other animal ſubſtance, and then the reſt of the veſſel is filled with water. Being thus filled, there is a cover, which is ſcrewed down cloſe upon the mouth of the veſſel, ſo that no air within the veſſel can by any means eſcape, nor any of the external air enter. Then the whole is placed over the flame of a lamp, or upon a few embers. In leſs than eight minutes time, the fleſh contained will be converted entirely into a liquor like ſoup. By encreaſing the fire a little more, or lengthening the time a few minutes longer, the hardeſt bones will be diſſolved down into a jelly. This utenſil was firſt invented by a philoſopher: it is at preſent chiefly converted to very unphiloſophical purpoſes; for it is merely an inſtrument of Epicuriſm and luxury. The French make their ſoups with it, and we have of late brought it among ourſelves from the elaboratory to the larder. When we conſider the force which the air muſt exert in thus bruiſing down, if I may ſo ſay, the hardeſt bones in a few minutes into an impalpable jelly, it may well excite our ſurpriſe,

priſe. The heavieſt hammer of an iron-work could not do it the fortieth part ſo ſoon. This inſtrument, as we ſaid, is called a Digeſter, for it was brought by Papin to explain the manner in which our food was digeſted in the ſtomach, which he compared to this machine. He found, that in four and twenty hours an heat equal to that of the human body would diſſolve the hardeſt bones in his digeſter, and he therefore ſuppoſed, that the heat in the ſtomach rarefying the air which was contained in the food, wrought the ſame change upon it, and diſſolved what we eat into a ſort of jelly, which is called chyle. A ſingle objection deſtroyed this whole theory. Fiſhes have no heat in their ſtomachs, but yet digeſt very quickly. This therefore, like ſeveral former opinions, was ſoon abandoned. Boerhaave, finding any one of the former opinions unequal to the explanation of the work of digeſtion, prudently united them all: a method the fitteſt, if not of ſatisfying curioſity, at leaſt of concealing ignorance.

WHEN we conſider this power, which heat has of rarefying the air, we cannot be ſo much ſurpriſed at the conſtant changes of weight and elaſticity, to which we find it liable; for, ſetting aſide the approach of the ſun, the earth is continually ſending up hot exhalations, which tend to rarefy the air in ſome places more than in others. Theſe changes of the air is what, in ſome meaſure, carries on the work of vegetation. Let us only conceive the air as cloſely enveloping the growing plant, and by its elaſticity inſinuating itſelf continually into its pores. Its continual dilatation and contraction will therefore take place upon entering the ſmall veſſels of the plant; for as its denſity is never found in nature two minutes together the ſame, it will be varying within the plant juſt as it was before its entrance. Thus in every plant there is a continual vibration of parts, the air contracting and dilating with the minuteſt variations of heat and cold. And thus it is that the juices are driven forward through their channels, and the whole work of vegetation is carried regularly on. And hence alſo it is, that plants will not vegetate in the void. I have often ſeen in a clear ſunſhiny day all the objects of nature as if trembling before my eyes. This is uſually aſcribed to the riſing of vapours; perhaps with more probability it may be attributed to this alternate expanſion and contraction of the air. This undulation is very manifeſt in the ſpiracles of many plants viewed with the microſcope. We find a ſimilar undulation in the parts of light. From analogy we may aſcribe ſuch ſimilar motion to the alternate expanſion and contraction of the air. At the worſt, if it be an error, the error is but ſmall, for the enquiry is of little importance.

CHAP. VII.

Of the Atmoſphere and its Height.

WE have ſeen the manner in which the air ſuſpends quickſilver in the empty tube to the height of about twenty-nine inches, and water to the height of about thirty-two feet: the quickſilver or water, however, as we ſaid, does not always riſe to the ſame height: the quickſilver, for inſtance, alters ſo as to be three inches lower, or three inches higher, at one time than at another. So that in the barometer or weather-glaſs there is a variation of three inches at leaſt between its higheſt and its loweſt ſuſpenſion. Theſe changes, as we alſo obſerved, muſt be aſcribed to the alteration of the weight of the air, ſometimes preſſing the external quickſilver with greater, ſometimes with leſſer force. If the quickſilver always ſtood at the ſame height, that is, exactly at twenty-nine inches, the weight of a pillar of the atmoſphere would be concluded to be invariable; and, as we ſhewed before, would be equal to a pillar of quickſilver twenty-nine inches high, and it would weigh above thirty thouſand pounds; but as the barometer is continually altering, it is plain the weight of the atmoſphere is altering alſo, inſomuch that it is near one tenth more heavy at one time than at another. For ſuppoſe, when the air is lighteſt, we at one time ſuſtain a weight equal to a pillar of quickſilver twenty-eight inches high, it is obvious that when, at another time, this pillar is encreaſed by three inches of quickſilver more, this will make our load near one tenth part more; or, in other words, if we at one time ſuſtain a pillar of air equal in weight to twenty-eight of theſe inches, which in round numbers is near thirty thouſand pound, we ſhall at another time, when the air is heavieſt, be loaded with a pillar of air equal to thirty-one inches of quickſilver, which will add to our load of thirty thouſand pound, near one tenth, that is, make it thirty-three thouſand pound.

Such is the difference of weight, which we inſenſibly ſuſtain at one time more than at another. Of the encreaſe of this preſſure other animals ſeem much more ſenſible than we: crows, for inſtance, as the poet has remarked, by their cawing ſurely foretel a change of weather: their more poignant ſenſations diſcover the approaching alteration, which perhaps the luxury, and artificial heats, to which we have accuſtomed ourſelves, have deprived us of. Certain it is, that in ſome parts of India, where the Joqueſe prieſts never eat animal food, nor ever enter houſes, their ſenſations of approaching change in the weather are ſaid to be exquiſite: they feel its weight, and their ſmell diſcovers its alterations. It is common among them, when deſcribing the beauties of a place, to rank among the number the exquiſite *taſte* of its air.

WE have already obſerved, that the greatneſs of the atmoſphere's weight did not affect us with a ſenſe of any oppreſſion, and we may remark the ſame with regard to the encreaſe of this weight. Nature hath wiſely armed us againſt this change, and in proportion as the atmoſphere is laid upon us with additional oppreſſion, the heart beats quicker againſt it, and drives the compreſſed fluids of the body with greater force. Why the heart thus bounds more ſtrongly when the weight of the atmoſphere is greateſt, we can but obſcurely tell: it is an enquiry rather belonging to the medical phyſiologiſt, than to the natural philoſopher. To whomſoever it belongs, the inveſtigation is abſtruſe, and the ſolution difficult.

AS we know with ſome preciſion the weight of our atmoſphere, ſo ſome philoſophers have purſued ſpeculation, and attempted to diſcover its height alſo. Geometricians love to purſue a ſubject where calculation is all that is neceſſary; for this reaſon we have had many ſolutions of this queſtion, and all different from each other.

If the air was not elaſtic, but throughout of the ſame denſity from the ſurface of the earth to the top of the atmoſphere, like water, which is equally denſe at every height, it would then be an eaſy taſk to meaſure the height of the atmoſphere. We might then proceed certainly and ſafely thus. We have only to find out the proportion between the height of a ſhort pillar of air, and a ſmall pillar of water of equal weight; and having compared the proportion the heights of theſe bear to each other in the ſmall, the ſame proportion will be ſure to hold in the great, between a pillar of water thirty-two feet high, and a pillar of air that reaches to the top of the atmoſphere,

ſphere, whoſe height I want to know. Thus, for inſtance, we find that a certain weight of water reaches one inch high, and a ſimilar weight of air reaches ſeventy-two feet high: this then is the proportion two ſuch pillars bear to each other in the ſmall. Now, if one inch of water be equal to ſeventy-two feet of air, to how much air will thirty-two feet of water be equal. By the common rule of proportion, I readily find, that thirty-two feet, or 384 inches of water, will be equal to 331,776 inches, which makes ſomething more than five miles, which would be the height of the atmoſphere, were its denſity every where the ſame as at the earth, where ſeventy-two feet of air were equal to one inch of water.

BUT this is not really the caſe; for the air's denſity, as we ſhewed before, is not every where the ſame, but decreaſes as the preſſure upon it decreaſes; ſo that the air becomes lighter and lighter the higher we aſcend, and at the upper part of the atmoſphere, where the preſſure is ſcarce any thing at all, the air dilating in proportion, muſt be expanded to a ſurpriſing degree; and therefore the height of the atmoſphere muſt be much greater than has appeared by the laſt calculation, in which its denſity was ſuppoſed to be every where as great as at the ſurface of the earth. In order therefore to determine the height of the atmoſphere more exactly, geometricians have endeavoured to determine the denſity of the air at different diſtances from the earth. The following ſketch will give an idea of the method which ſome geometricians have taken to determine this denſity, which is preparatory to finding out the height of the atmoſphere more exactly.

LET us ſuppoſe a pillar of air to reach from the top of the atmoſphere down to the earth's ſurface; and let us alſo ſuppoſe it marked like a ſtandard by inches, from the top to the bottom; let us ſtill farther ſuppoſe, that each inch of air, if not at all compreſſed, would weigh one grain. The topmoſt inch then weighs one grain, as it ſuffers no compreſſure whatſoever; the ſecond inch is preſſed by the topmoſt with a weight of one grain, and this added to its own natural weight or denſity of one grain, now makes its denſity, which is ever equal to the preſſure, two grains. The third inch is preſſed down by the weight of the two inches above it, whoſe weights united make three grains, and theſe added to its natural weight, give it a denſity of four grains. The fourth inch is preſſed by the united weight of the three above it, which together make ſeven grains, and this added to its natural weight give it a denſity of eight grains. The fifth inch, being preſſed by all the former fifteen, and its own weight, added, gives it a denſity of ſixteen grains, and ſo on, deſcending downwards to the bottom. The firſt inch has a denſity of one, the ſecond inch a denſity of two, the third inch, a denſity of four, the fourth inch of eight, the fifth of ſixteen, and ſo on. Thus the inches of air increaſe in denſity as they deſcend from the top, at the rate of one, two, four, eight, ſixteen, thirty-two, ſixty-four, and ſo on, which is called a geometrical progreſſion. Or if we have a mind to take this backwards, and begin at the bottom, we may ſay, that the denſity of each of theſe inches grows leſs upwards in a geometrical progreſſion. If, inſtead of inches, we ſuppoſe the parts into which this pillar of air is divided to be extremely ſmall, like thoſe of air, the rule will hold good in theſe as well as thoſe. So that we may generally aſſert, that the denſity of the air, from the ſurface of the earth, decreaſes in a geometrical proportion.

THIS being underſtood, ſhould I now deſire to know the denſity of the air at any certain height, I have only firſt to find out how much the denſity of the air is diminiſhed to a certain ſtandard height, and from thence proceed to tell how much it will be diminiſhed at the greateſt heights that can be imagined. At ſmall heights the diminution of its denſity is by fractional or broken numbers. We will ſuppoſe at once then, for greater eaſe, that at the height of five miles, or a Dutch league, the air is twice leſs denſe than at the ſurface of the earth: then, at two leagues high, it muſt be four times thinner and leſs denſe, and at three leagues eight times thinner and lighter, and ſo on. Inſtead of Dutch leagues, ſuppoſe we took a German league of ſeven miles, and that it was four times leſs denſe at the height of the firſt German league, then it would decreaſe in the ſame proportion, and be four times leſs denſe than the firſt at the ſecond league, that is ſixteen times; and four times leſs denſe than the ſecond at the third league, that is ſixty-four times; and four times leſs denſe than the third at the fourth league, that is two hundred and fifty-ſix times leſs denſe than at the ſurface. In ſhort, whatever decreaſe it received in the firſt ſtep, it will continue to have in the ſame proportion in the ſecond, third, and ſo on; and this, as we ſaid, is called geometrical progreſſion. They who are fond of calculations may go ſtill forward, calculating the height of the air in this manner, and they will find, that a cubic inch of ſuch air as we breathe here below would be ſo very much rarefied at the height of five hundred miles, that it would fill a ſphere equal in magnitude to the fartheſt reach of our planetary ſyſtem. Calculations, however, confer but little wiſdom.

By this method of calculating the denſity of the air, we find that the height of the atmoſphere is ſcarce to be determined, as it grows thinner the higher it aſcends. However, I think it may be eaſily enough proved, that it cannot diffuſe itſelf above a certain determined height; for it muſt be noted, that the air is attracted by gravity to the earth, all the time it is thus impelled to recede from it by its expanſive force. Now, if its denſity, and conſequently its expanſive force, which is equal, be ninety hundred thouſand million times leſs at one hundred miles from the earth, than at its ſurface, as is nearly the caſe; and if, on the other hand, the power of gravity ſhould be but a ſingle tenth part leſs at an hundred miles diſtance, than it is at the ſurface of the earth, it is evident, that the power of gravity will become at laſt greater than the force of expanſion, and at a certain height the air, inſtead of ſuffering farther expanſion, will be attracted towards the earth. For inſtance, ſuppoſe a bubble of air at the ſurface of the earth weighs but the millionth part of a grain, ſuppoſe it raiſed ſeventy miles high, its weight or gravity will ſcarce be diminiſhed at all, but its denſity, and conſequently its expanſive force, will be a million times leſs than before. Suppoſe then it is raiſed ſeventy-ſeven miles high, this will make ſcarce any alteration in its gravity; but its denſity, and conſequently its expanſive force, will be four million times leſs. Here then the gravitating force exceeds the expanſive force by three millions, and conſequently the particles of air, inſtead of attempting to riſe by expanſion, will be carried down by the ſuperior force of gravity. In other words, the atmoſphere cannot riſe above ſeventy miles high at the moſt.

IT were to be wiſhed, that this theory were aſcertained by experiment, and that upon examining the diminution of the air's denſity at three different heights, as in the valley, on the brow of a high mountain, and on its ſummit, we found the denſity of the air thus decreaſing in geometrical proportion. Were the theory thus inconteſtably aſcertained, and found conformable to facts, we might eaſily meaſure the heights of mountains merely by knowing the denſity of the air, and the air's denſity could always be eaſily found by the barometer. Derham, if I remember right, was the firſt who thought upon this method of meaſuring the heights of mountains by the barometer. He attempted to meaſure the hill of Snowdon in this manner: however, he ſuppoſed the atmoſphere of an equal denſity throughout. Others have taken its geometrically decreaſing denſity into conſideration, and laid down rules for thus meaſuring mountains by calculating their heights, in proportion to the decreaſe of the air's denſity. The thing is eaſily enough done; but at preſent, the whole of the method is looked upon as matter rather curious than either uſeful or exact. Caſſini the younger, in his admeaſurement of a degree in France, calculated the denſities of the air at ſeveral heights, upon different mountains; and he found the denſity of the air decreaſe in a much greater proportion as he aſcended, than in the geometrical progreſſion which the theory had laid down. The publication of theſe experiments cauſed a ſchiſm among naturaliſts. Some have aſcribed this difference between experiment and theory to the vapours being in greater abundance in the valley than on the mountain, and as theſe vapours neither riſe to the heights of pure air, nor act with equal elaſticity, the air upon the tops of mountains being freed from theſe is more expanded, and conſequently leſs denſe. This is denied by others, particularly Fontenelle: he aſſerts, that the air is more rare upon the tops of mountains, becauſe there it has more elaſticity, and it has there more elaſticity becauſe it has more humidity; but Dr. Jurin has well confuted this by ſhewing, that humidity by no means increaſes the elaſticity of the air. Others there are, who make a diſtinction between the air on the mountain, and the air in the valley, and who think that they are governed by different laws. Such is the ſtate of the controverſy as it ſtill ſubſiſts. Philoſophers diſpute, but chance more frequently decides.

THIS method of determining the height of the atmoſphere, though perhaps the beſt, is yet diſliked by Bernouilli, who gives us a method of his own. The heat in the air is reckoned by him as one of the agents in producing its different denſities. This method, however, is not much followed: the manner of finding out its height, as given by Kepler, is moſt known and followed, though perhaps built, like the reſt, upon a baſeleſs foundation. Kepler's method is this.

ASTRONOMERS know, to the greateſt exactneſs, the place of the heavens in which the ſun is at any one moment of time: they know, for inſtance, the moment in which it will ſet, and alſo the preciſe time in which it is about to riſe. However, upon awaiting his appearance any morning, they always ſee the light of the ſun before its body, and they ſee the ſun itſelf ſome minutes ſooner above the mountain top, than it ought to appear from their calculations. Twilight they ſee long before the ſun appears, and that at a time when they know that it is eighteen degrees lower than the verge of the ſky. There is then in this caſe ſomething which deceives our ſight; for we cannot ſuppoſe the ſun to be ſo irregular in his motions as to vary every morning: this would diſturb the regularity of nature. The deception actually exiſts in the atmoſphere. By looking through this denſe, tranſparent ſubſtance, every celeſtial object that lies beyond it is ſeemingly raiſed up, in ſome ſuch manner as we ſee a piece of money look as if raiſed higher in a baſon filled with water. From hence it is plain, that if the atmoſphere were away, the ſun's light would not be brought to view ſo long in the morning before the ſun itſelf actually appears. The ſun, without the atmoſphere, would appear all blazing in light the inſtant it roſe, and leave us in total darkneſs the inſtant of its ſetting. The length of the twilight, therefore, is in proportion to the height of the atmoſphere; or let us invert this and ſay, that the height of the atmoſphere is in proportion to the length of the twilight. So that the diſtance there is between the real and the apparent place of the ſun's ray will ſerve to meaſure the height of the atmoſphere; for let us ſuppoſe the ſun to be at S, and the eye of a ſpectator upon the earth at A. Now the ſpectator cannot ſee the ſun, but yet he will ſee the light reflected by the atmoſphere; for when the ray of the ſun touches the earth at D, (ſee fig. 52.) and goes ſtill forward, as ſoon as it arrives at B it will bend ſlanting to the ſpectator's eye at A; by which he enjoys the light before the ſun appears. This ray has touched the earth at D and at A, and the arch DA is comprehended between the two tangents. If a line be drawn from the centre of the earth, ſo as to divide this arch in two equal parts, from the nature of all circles, as geometry aſſures us, it muſt come upon the place where the ray was bended at B, and the length of the line HB will be the height of the atmoſphere,

ſphere, which even a common ſurveyor may eaſily find. It is generally found by this means to be about forty-five miles high. All this holds, ſuppoſing the rays to be ſtraight or direct as they paſs through the atmoſphere, which in fact they are not. Kepler was the firſt who found out this, but he ſoon abandoned it, becauſe it made the atmoſphere many times higher than he really thought it was.

HOWEVER this be, twilight is one of the great bleſſings we derive from our atmoſphere: by it we are by gentle degrees brought from darkneſs into light, and again from light into darkneſs. In thoſe countries towards the poles, where, though the ſun diſappears totally for a ſeaſon, yet, when not above eighteen degrees below their horizon, they have the twilight all night long. At the equator, the twilight is ſhorteſt, becauſe the rays of the ſun dart moſt directly through the atmoſphere, and conſequently are leſs refracted by paſſing through it; but even allowing the whole of this computation to be exact, which however the learned now begin to doubt of, yet there muſt be allowance ſtill made for the alterations in the denſity of the atmoſphere; for the denſer it is, the greater will be its power of refracting the light, and we ſhewed before that cold will encreaſe its denſity. In Nova Zembla, where the air is extremely cold, the refracting power of the atmoſphere is ſo great, that ſome Hollanders, who wintered there, were ſurpriſed to ſee the ſun ſeventeen days before they expected to ſee him, even allowing for the influence of the atmoſphere, as aſtronomers uſually do. There is another appearance in the heavens uſually aſcribed to the atmoſphere, the largeneſs of the riſing or ſetting ſun or moon, and their oval appearance; but as theſe can be explained only by the aſſiſtance of optics, they muſt be reſerved for that part of natural philoſophy.

BESIDE theſe benefits which we derive from our atmoſphere, muſt be mentioned that of its ſurrounding the earth on every ſide, and turning with it as the earth turns. Were it not for this, the tenants of the earth's ſurface might be every moment liable, perhaps, to the ſhocks of that fine fluid with which our planetary ſyſtem is, by moſt moderns, thought to be filled. The parts of light itſelf might make a violent impreſſion upon us, if we were daſhed againſt them by the earth's rapid rotation, unſhielded by our atmoſphere.

CHAP. VIII.

Of WINDS.

WE have already repreſented the atmoſphere as in continual motion, alternately relaxed by heat, and contracted by cold, as the ſun, our ſource of celeſtial heat, acts upon it, or the hot or cold exhalations from the earth contribute to encreaſe its warmth or to diminiſh it.

IF we ſhould move with great ſpeed againſt the air, we ſhould feel its force: the ſame thing will happen if the air moves with ſwiftneſs againſt us: we feel it forcibly impreſſed upon our bodies, and the air thus moving all know to be called Wind. The wind is nothing elſe but the air put violently into motion, and the more ſwift this motion, and the more denſe the air, the greater the wind's force, and if to a great degree, it is then called a Storm.

If we ſuppoſe the atmoſphere heated in any one part more violently than in another, it is plain, that this will dilate it, and drive the air out of that part. The air, however, cannot be thus driven from its own peculiar place without making an excurſion into the place which another body of air poſſeſſes. By this means a great quantity of air will be crowded or condenſed into one particular region, while another ſhall have but very little. This inequality of the air in theſe two different regions muſt continue as long as the one of them continues more heated by the ſun or by vapours than the other. But when the cauſe of the inequality is removed, and the heat is equally moderate in both places, the air condenſed in one place having nothing now to reſiſt its preſſure, will ruſh into the place empty of air, and thus flowing in with a violent motion produce winds, ſuch as we every hour experience. To have a clear conception of this, let us compare that particular ſpot or place where all the air is juſt in a manner exhauſted by heat to a great empty gulf, into which fluids are going to enter from every ſide. The inhabitants in the midſt of the gulf are preſſed violently by the ſtream on every ſide: thoſe who are to the north of it, ſee the ſtream of air directed towards the ſouth, that is, they have a north wind: thoſe on the contrary, who live to the ſouthward, ſee the ſtream going northwards, and therefore have a ſouth wind, and ſo of all the other points of the compaſs. In the midſt of the gulf, where all the ſtreams meet and mix, they feel all the inconveniences which are the effects of that heterogeneous mixture. There ſulphureous exhalations from the ſouth, torrents of nitre from the north, and watery vapours from every ſide, are indiſcriminately blended together in one confuſed maſs. From hence proceed tempeſts, thunder, rain, hail, and whirlwinds.

BUT though winds are thus found to produce miſchief, yet the harm they do bears no proportion to the good we experience from them. The atmoſphere of a large city, if continually the ſame, would ſoon become corrupt, and from the quantity of animal exhalations floating in it, would in a very few days, perhaps hours, deſtroy the health of the inhabitants. The wind prevents this, and blows away this over-charged part of the atmoſphere, placing a new column of atmoſphere in its room.

THESE currents of air are alſo beneficial in another reſpect, for they often cool the atmoſphere when too much heated. Thoſe places, which have but juſt before felt the moſt violent effects of heat, are refreſhed by the air which comes from a colder region. On the other hand, the air, which by heat has been forced from the warmer region into that which is more cold, reciprocally benefits that, and ſoftens the ſeverity of its natural atmoſphere. The inhabitants of thoſe iſlands that lie in hot tropical climates feel theſe benefits moſt ſignally from the wind. All day the ſun beating with ſeverity againſt the ſolid earth of the iſland, cauſes this, like all hard ſubſtances, to be greatly heated, and the air conſequently rarefied to a great degree. In the mean time, the air upon the ſurface of ſo great and ſo fluid a body as the ſurrounding ocean, is by no means ſo much rarefied, but lies out cool at ſea, and conſequently healthful. As ſoon, therefore, as the ſun every day has done exerting the violence of his heat, the air from the ocean pours in upon the inhabitants panting and faint for want of air, and at once comforts, cools, and refreſhes them. Thus every four-and-twenty hours they have two regular and ſtated winds. In the morning, while the ſun is driving off the air from land, the wind blows out to ſea; on the contrary, when the ſun's power is over, and he has done his taſk, at night the air from the ſea ruſhes back to fill the ſpace the ſun had made empty.

In this manner, however irregular we find the wind in this ſtill happier climate, they have it a more conſtant and more grateful viſitant; yet the conſtancy of the wind among the iſlands is but a trifle, if compared to what it is found to blow in the open parts of the ocean between the tropics; for in general, within the whole torrid zone, an eaſt wind is found to prevail throughout the whole year: ſo that if a ſhip ſhould ſail away from the coaſt of Africa, and go continually weſtward, it would have an eaſtern gale to carry it round the whole globe. From its being ſo favourable to navigation, this wind has been called a Trade Wind.

The cauſe of this conſtancy in the trade winds has been variouſly accounted for. Very many, and very abſurd have been the conjectures brought to explain them. There is a weed, ſays Lyſter, growing in the ſea, called *alga marina*, and extremely abundant in the tropical climates. The perſpirations of this weed produce air, and this air produces the trade winds, and theſe trade winds are always conſtant, becauſe they are always produced from the ſame plant. This is ſufficiently abſurd.

DR. GORDON, with more probability, aſcribed the trade wind to the motion of the earth upon its axle; but none of the motions of a fluid at the earth's ſurface can be aſcribed to that cauſe. Others were willing to aſcribe them to the ſame cauſes that produced the tides, the ſun and moon's attraction. But it might be geometrically proved, that this attraction would not cauſe the air to riſe much higher than it does the ocean, which in the air would be ſo trifling a difference, that it could cauſe no ſenſible alteration whatever in the direction of the winds. It is to Dr. Halley we owe the moſt rational theory upon this ſubject.

He explains the cauſe of the trade-winds in general terms thus: the air is more rarefied between the tropics, becauſe a greater quantity of the ſun's rays fall in that region, and becauſe they fall more directly, and alſo becauſe it is that part of the earth which is actually nearer the ſun. Now, as the ſun travels onward from eaſt to weſt every day, he dilates moſt that part of the atmoſphere that is immediately under him, and ſo makes a kind of a void ſpace as he goes along; but it is very obvious, that the air behind him will ruſh in to fill up this ſpace that he has juſt left, rather than the air which is before his motion: for if the air before his motion ruſhed forward to fill up the chaſm he has juſt made, it muſt paſs directly under his rays, and if ſo it would itſelf by that means be dilated, and ſo rendered unfit to fill up the void place it was ruſhing in to occupy. For this reaſon, therefore, the air muſt follow the ſun's motion, and fill each chaſm he has juſt made; in other words, the trade-winds muſt move from eaſt to weſt. From hence, therefore, between the tropics, there would always be a current of air due eaſt; but we are to take another effect into conſideration. The denſe air from the north and ſouth poles is always ruſhing into the rarefied regions of the equator. Here theſe two oppoſite winds meeting with that which continually blows due eaſt, they in ſome meaſure flow in its current, and in ſome meaſure keep their own current. On the north ſide of the equator the wind blows north-eaſt; on the ſouth ſide of the equator it conſtantly blows ſouth-eaſt; and this is really the caſe with the trade-winds, which lie over the open part of the ocean, and which are not affected by the heat, which the ſun ſtriking againſt ſome neighbouring continent might produce.

I SAY in the open parts of the ocean; for in thoſe parts of it crowded with iſlands, or lying near continents, the trade-winds are by no means ſo regular. Earth is a more hard body than water;

hard bodies receive a ſtronger heat than thoſe which are fluid; an iron heated red-hot is much hotter than water at its higheſt pitch of heat; the earth, as being an harder body than the ocean, receives more of the ſun's rays, and reflects them with greater violence. Thus the air over a large continent is much more heated, and therefore more dilated, than over an ocean. This difference, therefore, produces what mariners in thoſe climates call the Land-wind. Every day, while the ſun heats the earth, and thus produces a dilatation, the air is in a manner driven out to ſea; but at night, when this heat ceaſes, the ſea-breeze blows in upon land to fill up the void cauſed by the diurnal ſolar heat. Thus it is where there are continents, or iſlands, lying between the tropics: by day the wind blows out from ſhore; by night, it blows back again the contrary way, and mariners find it dangerous to attempt landing at that time; but it is otherwiſe where the ocean is open. Such is the regularity of the trade-winds, in ſuch circumſtances, that from the moſt weſtern coaſt of America acroſs the great Pacific Ocean to the Philippine Iſlands, is but a voyage of nine weeks; for the ocean is almoſt without iſland, and the winds upon its ſurface blow continually the ſame way.

SUCH therefore is the nature of the winds, that if the earth were all over covered with one deep ocean, the winds upon its ſurface would always blow the ſame way on either ſide of the equator, and the motion of the air would regularly purſue the motion of the ſun; but in the earth's preſent ſtate, there are numberleſs cauſes to interrupt their regularity, and more in our colder climates than in thoſe burning regions that are more immediately ſubject to the ſun's influence. In theſe there is a kind of interrupted regularity in the winds, but with us nothing can be more irregular than they are. The ſun is ſeldom ſo extremely powerful in the temperate zone, as to counteract the inconſtant and uncertain impreſſions of different exhalations upon the wind, and thus give regularity to its motions. Vapours, meteors, mountains, foreſts, lakes, cities, all conſpire to give a new direction to the current of the air, and alter the ſtate of the atmoſphere. The cauſes that give irregularity to winds with us are numerous, while the ſun, that in the torrid climates regulates their motion, operates here with diminiſhed influence. We have not yet, therefore, a ſufficient hiſtory of the changes wrought by theſe different cauſes upon the wind in our own climates; and until ſuch an hiſtory, which muſt be the work of more than an age, can be compiled, no certainty is to be expected in our predictions of the changes it may undergo. Bacon was the firſt who undertook to write an hiſtory of the wind: his great ſpirit was deterred at no difficulty in the way; he began the edifice, and ſucceeding philoſophers, inſtead of purſuing his great deſign, have left it ſtanding juſt at the height he left it. They have added ſcarce any new obſervations to enlarge the work. Had his plan been carried on with the ſame ſpirit with which he began it, the variations of the weather might now perhaps have been determined with greater certainty, and who knows but by this time we might have been able to predict a north or a ſouth wind, with as much exactneſs as we now calculate an eclipſe. To predict an eclipſe is an object merely of curioſity; to predict an approaching ſtorm would be of inconceivable benefit. The time ſpent in determining the figure of a *tautochrone* might have been more uſefully employed in this reſearch. I ſhall conclude this chapter with the ſketch of an hiſtory of the winds, ſuch as he has left it, with ſome few additions by Halley, Buffon, D'Alembert, and others.

AT ſea the winds are more regular than at land; for there nothing oppoſes their progreſs, or alters the ſun's influence.

THE air at ſea is more equable, as well as more conſtant: at land it blows in fits of force and intermiſſion; but at ſea the current is ſtrong, ſteady, and even.

IN general, at ſea, on this ſide the equator, the eaſt and north winds are moſt violent and boiſterous: on the contrary, at land, the weſt and ſouth winds are moſt ſubject to produce hurricanes and tempeſts.

THE air is often ſeen to move in two contrary currents, and this almoſt ever previous to thunder. The clouds, in ſuch a caſe, are ſeen to move one way, while the weathercock points another.

THE winds are more violent at certain heights than upon the plain, and the higher we aſcend lofty mountains, the greater is the force of the wind, till we get above the ordinary heights of the clouds. Above this the ſky is uſually ſerene and clear. The reaſon is, that the wind, at the ſurface of the earth, is continually interrupted by hills and riſings: ſo that, on the plain, between any two of theſe, the inhabitants are in a kind of ſhelter; but when once the interpoſition of ſmall hills no longer ſtops the wind's courſe, it then becomes ſtronger, as the interruptions it meets with are fewer. At the tops of the higher mountains its interruptions are leaſt of all; but it does not blow with violence there: for its denſity is ſo much diminiſhed by the height, that its force is ſcarce perceivable, and the ſtorm falls midway below.

A current of air always augments in force in proportion as the paſſage through which it runs is diminiſhed. The law of this augmentation is, that the air's force is compounded of its ſwiftneſs and denſity, and as theſe are encreaſed, ſo will the force of the wind. If any quantity of wind moves with twice the ſwiftneſs of a ſimilar quantity, it will be twice as forceful; but if, at the ſame time that it is twice as ſwift, it moves through twice a ſmaller tube, and the ſides of the canal give no reſiſtance to its motion, it will be four times as forceful. This, however, is not entirely the caſe; for the ſides of the tube give a reſiſtance, and retard its motion, in a proportion that is not eaſily calculated. From this increaſe of the wind's denſity in blowing through narrow paſſages, it is that we ſee the ſtorms ſo very violent that ſometime blow between two neighbouring hills. It is from this, that when caught in long arcades opening at one end, the wind blows with great force along them. From this increaſed denſity it is, that we meet with ſuch cold blaſts at the corners of ſtreets. In ſhort, whatever diminiſhes its bulk, without taking entirely away from its motion, increaſes the vehemence of the wind. This alſo is the reaſon why the air reflected back from the ſide of a mountain is often more violent than the air which firſt ſtruck its ſide; for it is by this means condenſed, and its force augmented. The countrymen and farmers have a diſtinction which is not without its foundation; for they make a difference between a ſwift and an heavy ſtorm: the ſwift ſtorm is loud, boiſterous, and inoffenſive; the heavy ſtorm more ſo, but more forceful and dangerous. This ſhews the inſufficiency of thoſe inſtruments made for meaſuring winds, by meaſuring the rapidity only with which they move. Theſe machines for meaſuring the ſwiftneſs of the wind are called Anemometers, an ill-founding word made from Greek.

MR. BUFFON has divided the winds by zones: the frigid zone is the parent of north winds, and eaſt winds rule at the equator. The winds of the temperate zone are compoſed of the eddies of theſe two united. As the north wind prevails over the eaſt wind, it produces a weſt wind; as the eaſt wind prevails, it produces a wind from the ſouth. Theſe, however, are reflected, refracted, and at laſt deſtroyed by each other's oppoſition in every region: their force is greateſt when ſeveral winds conſpire to move in the ſame current.

So much may ſerve as a ſketch of this great undertaking. It is but very lately that we began to make obſervations on the changes of the weather: which may be conſidered as a noble and diſintereſted preſent to poſterity; for we can ſcarce expect to have them in ſufficient number in our own age, from whence to deduce any general theory that ſhall turn to public benefit.

CHAP IX.

Of Muſical Sounds.

THE ſenſe of ſounds adds infinitely more to the happineſs of man than to that of all other animals: it not only ſupplies him, like them, with expreſſions of his wants and his deſires, but it opens to him a wide field for pleaſure. He finds delights unknown to the reſt of the animated creation from their varied combinations. The fables of the ancients pretend, that muſic was firſt found out by the beating of different hammers upon the ſmith's anvil. Without purſuing the fable, let us endeavour to explain the nature of muſical ſounds by a ſimilar method; for fable may often conduct us to truth. Let us ſuppoſe an anvil, or ſeveral ſimilar anvils, to be ſtruck upon by ſeveral hammers of different weights or forces. The hammer, which is double that of another, upon ſtriking the anvil will produce a ſound double that of the other: this double ſound muſicians have agreed to call an Octave. The ear can judge of the difference or reſemblance of theſe ſounds with great eaſe, the numbers being as one and two, and therefore very readily compared. Suppoſe that an hammer three times leſs than the firſt, ſtrikes the anvil, the ſound produced by this will be three times leſs than the firſt: ſo that the ear, in judging the ſimilitude of theſe ſounds, will find ſomewhat more difficulty; becauſe it is not ſo eaſy to tell how often one is contained in three, as it is to tell how often it is contained in two. Again, ſuppoſe that an hammer four times leſs than the firſt ſtrikes the anvil, the ear will find greater difficulty ſtill in judging preciſely the difference of the ſounds; for the difference of the numbers four and one cannot ſo ſoon be determined with preciſion as three and one. If the hammer be five times leſs, the difficulty of judging will be ſtill greater. If the hammer be ſix times leſs, the difficulty ſtill increaſes, and ſo alſo of the ſeventh, inſomuch that the ear cannot always readily and at once determine the preciſe gradation. Now, of all compariſons, thoſe which the mind makes moſt eaſily, and with leaſt labour, are the moſt pleaſing. There is a certain regularity in the human ſoul, by which it finds happineſs in exact and ſtriking and eaſily-made compariſons. As the ear is but an inſtrument of the mind, it is therefore moſt pleaſed with the combination of any two ſounds, the differences of which it can moſt readily diſtinguiſh. It is more pleaſed with the concord of two ſounds, which are to each other as one and two, than of two ſounds, which are as one and three, or one and four, or one and five, or one and ſix or ſeven. Upon this pleaſure, which the mind takes in compariſon, all harmony depends. The variety of ſounds are infinite; but becauſe the ear cannot compare two ſounds ſo as readily to diſtinguiſh their diſcriminations when they exceed the proportion of one and ſeven, muſicians have been content to confine all harmony within that compaſs, and allowed but ſeven notes in muſical compoſition.

Let us now then ſuppoſe a ſtringed inſtrument fitted up in the order mentioned above. For inſtance: let the firſt ſtring be twice as long as the ſecond; let the third ſtring be three times ſhorter than the firſt, let the fourth be four times, the fifth ſtring five times, and the ſixth ſix times as ſhort as the firſt. Such an inſtrument would probably give us a repreſentation of the lyre as it came firſt from the hand of the inventor. This inſtrument will give us all the ſeven notes following each other, in the order in which any two of them will accord together moſt pleaſingly; but yet it will be a very inconvenient and a very diſagreeable inſtrument: inconvenient, for in a compaſs of ſeven ſtrings only the firſt muſt be ſeven times as long as the laſt; and diſagreeable, becauſe this firſt ſtring will be ſeven times as loud alſo: ſo that when the tones are to be played in a different order, loud and ſoft ſounds would be intermixed with moſt diſguſting alternations. In order to improve the firſt inſtrument, therefore, ſucceeding muſicians very judiciouſly threw in all the other ſtrings between the two firſt, or, in other words, between the two octaves, giving to each, however, the ſame proportion to what it would have had in the firſt natural inſtrument. This made the inſtrument more portable, and the ſounds more even and pleaſing. They therefore diſpoſed the ſounds between the octave in their natural order, and gave each its own proportional dimenſions. It is not my deſign here to enter farther into this ſubject than merely its ſlighteſt elements; let it therefore ſuffice to ſay that, in general, of theſe ſounds, where the proportion between any two of them is moſt obvious, the concord between them will be moſt pleaſing. Thus octaves, which are as two to one, have a moſt harmonious effect; the fourth and fifth alſo ſound ſweetly together, and they will be found, upon calculation, to bear the ſame proportion to each other that octaves do. "Let it not be ſuppoſed, (ſays Mr. Saveur) that the muſical ſcale is merely "an arbitrary combination of ſounds: "it is made up from the conſonance "and differences of the parts which "compoſe it. Thoſe who have often "heard a fourth and a fifth accord together, will be naturally led to diſcover "their difference at once; and the mind "unites itſelf to their beauties." Let us then ceaſe to aſſign the coincidences of vibrations as the cauſe of harmony, ſince theſe coincidences in two ſtrings vibrating at different intervals, muſt at beſt be but fortuitous, whereas concord is always pleaſing. The true cauſe why concord is pleaſing, muſt ariſe from our power, in ſuch a caſe, of meaſuring more eaſily the differences of the tones. In proportion as the note can be meaſured with its fundamental tone by large and obvious diſtinctions, then the concord is moſt pleaſing; on the contrary, when the ear meaſures the diſcriminations of two tones by very ſmall parts, or cannot meaſure them at all, it loſes the beauty of their reſemblance: the whole is diſcord and pain.

BUT there is another property in the vibration of a muſical ſtring not yet taken notice of, and which ſerves to confirm the foregoing theory. If we ſtrike the ſtring of an harpſichord, or any other elaſtic ſounding cord whatever, it returns a continuing ſound. This till of late was conſidered as one ſimple uniform tone; but all muſicians now confeſs, that inſtead of one tone it actually returns four tones, and that conſtantly. The notes are, beſide the fundamental tone, an octave above, a twelfth above, and a ſeventeenth. One of the baſe notes of an harpſichord has been diſſected in this manner by Mr. Rameau, and the actual exiſtence of theſe tones proved beyond a poſſibility of being controverted. In fact, the experiment is eaſily tried; for if we ſmartly ſtrike one of the lower keys of an harpſichord, and then take the finger briſkly away, a tolerable ear will be able to diſtinguiſh, that after the fundamental tone has ceaſed, three other ſhriller tones will be diſtinctly heard: firſt the octave above, then the twelfth, and laſtly the ſeventeenth: the octave above is in general almoſt mixed with the fundamental tone, ſo as not to be eaſily perceived, except by an ear long habituated to the minute diſcriminations of ſounds. So that we may obſerve, that the ſmalleſt tone is heard laſt, and the deepeſt or largeſt tone firſt: the two others in order.

In the whole theory of ſounds, nothing has given greater room for ſpeculation, conjecture, and diſappointment, than this amazing property in elaſtic ſtrings. The whole ſtring is univerſally acknowledged to be in vibration in all its parts, yet this ſingle vibration returns no leſs than four different ſounds. They who account for the tones of ſtrings by the number of their vibrations are here at the greateſt loſs. Daniel Bernoüilli ſuppoſes, that a vibrating ſtring divides itſelf into a number of curves, each of which has a peculiar vibration, and though they all ſwing together in the common vibration, yet each vibrates within itſelf. This opinion, which was ſupported, as moſt geometrical ſpeculations are, with the parade of demonſtration, was only born ſoon after to die. Others have aſcribed this to an elaſtic difference in the parts of the air, each of which, at different intervals, thus received different impreſſions from the ſtring, in proportion to their elaſticity. This is abſurd. If we allow the difference of tone to proceed from the force, and not the frequency of the vibrations, this difficulty will admit of an eaſy ſolution. Theſe ſounds, though they ſeem to exiſt together in the ſtring, actually follow each other in ſucceſſion: while the vibration has greateſt force, the fundamental tone is brought forward: the force of the vibration decaying, the octave is produced, but almoſt only inſtantaneouſly; to this ſucceeds, with diminiſhed force, the twelfth, and laſtly the ſeventeenth is heard to vibrate with great diſtinctneſs, while the three other tones are always ſilent. Theſe ſounds, thus excited, are all of them the harmonic tones, whoſe differences from the fundamental tone are, as we ſaid, ſtrong and diſtinct. On the other hand, the diſcordant tones cannot be heard, their differences being but very ſmall are overpowered, and in a manner drowned in the tones of ſuperior difference: yet not always neither; for Daniel Bernouilli has been able, from the ſame ſtroke, to make the ſame ſtring bring out its harmonic and its diſcordant tones alſo*. So that from hence we may juſtly infer, that every note whatſoever is only a ſucceſſion of tones, and that thoſe are moſt diſtinctly heard, whoſe differences are moſt eaſily perceivable. Thus far then we ſee a ſtrong ſimilitude between a tone of ſound and a ray of light: both are, to all appearance, ſimple and uniform; but art can diſſect them, and in ſome meaſure diſcover their conſtituent principles.

I WOULD only obſerve here farther, that of all the ſounds I have hitherto experienced, thoſe brought from the edge of the muſical glaſs are moſt ſimple and uniform. The great pleaſure they give is from their ſimplicity alone; for when three, or any other number of them, come to be united together into one harmony, the ſounds are low, trifling, confuſed, and ſcarce ſuperior to that of a jews-harp. So that we ſee how injudiciouſly the performers on glaſſes manage, who play firſts, ſeconds, and ſometimes a baſe altogether upon an inſtrument, whoſe only excellence depends, not on its ſtrength, but its ſimplicity of tone.

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* Vid. Memoires de l'Académie de Berlin, 1753, p. 153.

To recapitulate all that has been ſaid upon the ſubject of ſounds: long continued tones are nothing more than a repetition of the ſame ſtroke and tone. By ſwiftly repeating the ſtrokes, all bodies are capable of giving tones; but theſe tones do not ariſe from the ſwiftneſs but the greatneſs of the blow. The tone, therefore, in elaſtic ſtrings, is not to be attributed to the frequency of the vibration, but to its force, to that greater vehemence with which a long and thick ſtring, permitted by proper tenſion to exert its whole elaſtic power, excels a ſhort and ſmall ſtring ſcrewed up almoſt beyond its pitch of elaſticity. The quantity of vibration is always proportioned to the length, diameter, and diminiſhed tenſion of the ſtring; but the quantity or depth of tone is not always ſo. Yet, notwithſtanding this, in practically tuning moſt muſical inſtruments, as the tone and vibrations ariſe from the ſame cauſe, and are uſually ſimilar, the vibrations will ſerve to meaſure the tone. But then, when we conſider the ſubject philoſophically, we ſhould not call thoſe vibrations the parent, when they are only the ſiſter of muſical ſounds. Light and flame are ever ſeen together, and yet it would be unjuſt to ſay that light is the parent of flame. True thinking is nothing more than giving effects their proper cauſes.

I CANNOT quit a ſubject relative to an art, of which I am ſo fond, without making a few ſlight remarks upon Engliſh muſical compoſition in general. Foreigners greatly object to our harmonies: they accuſe them of being almoſt always overcharged, and that there is never room enough left for occaſional force of expreſſion. Whether their diſlike to Handel be juſt or not, I will not pretend to determine; but certain it is, they ſeem highly diſpleaſed with his ſtile and manner, nor will they bear to hear him named with Haſſe, Pergoleſe, Faradellas, or any of the principal foreign compoſers. The fire of his muſic, as they expreſs it, is much too great, and generally unfitted to the ſubject and the performers. They ſhould have conſidered, however, that it is in general adapted to the audience: the Engliſh have been ever remarked for being fond of loud muſic. Scaliger, as early as the time of Queen Elizabeth, gives that peculiarity among the features of their national character. Handel ſeems to have ſtudied his audience perfectly: he knew that an Engliſh ear found leſs pleaſure in the ſound of a violin, than in the glorious notes of a drum.

IT has been objected by foreigners, that modern Engliſh muſic labours throughout under the abſurdity of miſtaken expreſſion. For inſtance: when it would expreſs any thing very high, the notes are raiſed high; if it would expreſs the wonders of the deep, the word *deep* is taken down to the loweſt note of the Diapaſon. Whereas, ſay they, depth and height have no reſemblance whatever, but in name, to the different tones of muſic. In the ſame manner, joy, ſorrow, and almoſt all the paſſions, are abſurdly expreſſed, ſo that no paſſion is really excited but that of mirth, while muſic thus forgets its dignity by deſcending to imitation.

IT has been objected by foreigners to modern Engliſh muſic, that the concert pitch has been injudiciouſly altered. There is, ſay they, a certain ſtretch, at which all ſtrings give their fineſt tones: that, in general, is the pitch which the other nations of Europe have found by experience to be their concert tone. In the colder climates, this pitch, if it be altered at all, ſhould be let down; for ſounds ſtrike briſker in a cold air than in a warm, in froſt, for inſtance, than in the ſultry heats of autumn. A humid air alſo braces the ſtring, and only adds to the tenſion of ſtrings already raiſed above their tonic pitch.

To all theſe objections I can only anſwer, that, whatever be our defects in this way, modern Italian muſic, (for the French need not be mentioned, as ſome will ſcarce allow that they have any) modern Italian muſic, I ſay, is ſtill more defective than ours. Whatever variety of expreſſion ours may want from too much harmony, theirs actually wants from a deficiency of genius. I have heard a judicious friend obſerve, that he thought all the modern Italian cantata's but a repetition of the ſame tune. In fact, though they at preſent aim ſo much at ſimplicity, contrary to what is uſually imagined upon this ſubject, I have heard a ſinger throw more ſong into his voluntary cloſe, than the compoſer had given him in his part. But in proportion as the compoſers are ſteril, their performers are compelled to be wild, and to make up in tawdry ornament what the piece wants in ſolidity. Muſic, notwithſtanding, muſt be owned to have been indebted for many improvements to ſome later compoſers. Alberti is graceful, Tartini delicate, Rameau, though a Frenchman, often ſublime; Handel's muſic is well adapted; but, after all, Correlli is ſtill inimitable.

THEY who would deſire a thorough knowledge of the mathematical principles, upon which the ſcience of muſical compoſition is founded, cannot have a better or more accurate guide than Smith's Treatiſe of Harmonics. They who would deſire to conſider the ſcience in a more practical light, may conſult a work ſome time ſince publiſhed by

Tartini, at Florence, entitled, *Trattato della Muſica,* in which he conſiders the ſcience both as a muſician and a philoſopher. Nor ſhould I paſs over the endeavours of Mr. Rameau upon this ſubject, in which he has attempted to give what he calls a new ſcale, conſiſting of eleven notes, each divided from the other by more exact proportions than in the preſent ſcale. This attempt, however, is not new. In fact, it is no more than the ancient ſcale, propoſed near two thouſand years ago by Ariſtoxenus. A new ſcale would be, at preſent, the ſame thing as to introduce among mankind, an univerſal language: both might be more commodious and more rational. However, men are better pleaſed with travelling in an old road that they know, though longer, than in finding out an unknown but ſhorter path, that may at beſt but conduct them to the ſame end, which the other did before.

CHAP. X.

Of Sound in general.

IF we were to examine all nature for a place proper for augmenting and echoing ſounds with moſt force, and with greateſt exactneſs, we ſhould find the human ear to be beſt formed for theſe purpoſes. By its admirable contrivance it repeats ſounds of all kinds, admits the greateſt quantity into the ſmalleſt ſpace, and echoes each back without confuſion. Within the ſkull there is a large bony canal, that has one end opening into the ear, and the other running backwards with ſeveral turnings, ſomewhat reſembling the internal windings of a common ſnail-ſhell. This labyrinth is lined within by a very fine ſkin, which is but an expanſion of the nerves that ſerve for hearing, and which, uniting together towards the bottom, carry the ſounds directly to the brain. But before the ſound can come to the labyrinth, it muſt neceſſarily ſtrike againſt a thin ſkin, which is ſtretched, like the parchment of a drum, acroſs a paſſage that leads from the outward ear into the mouth. This membrane or ſkin is called the drum of the ear, and, as in a common drum, there is a contrivance that ſeems calculated to brace or relax it at pleaſure. About the uſe of this drum modern phyſiologiſts are divided. The common opinion is, that all ſounds muſt firſt ſtrike againſt this, and make its parts vibrate like a beaten drum, and that this vibration is communicated to the internal labyrinth, whoſe tremors correſpond, and thus the ſound is carried to the brain. They go on alſo to affirm, that when the drum of the ear is either too much relaxed, or totally deſtroyed, there can be no tremors of ſound conveyed to the labyrinth, and that therefore the perſon muſt become deaf. This doctrine, however, is contradicted by others, who affirm, that perſons hear perfectly well who have been totally deprived of this ear-drum; that others drive tobacco ſmoak, which they take in at their mouths, through both ears, and as in its paſſage it muſt neceſſarily be ſtrained through the drum of the ear, (for there is no other way by which it can paſs) they are apt to think that this membrane, which admits ſo groſs a fluid, cannot be the proper inſtrument for hearing. Beſides all this, they affirm that birds, whoſe hearing is very exquiſite, are deprived of this apparatus, and therefore ſo may we, and yet ſtill continue to hear. Theſe objections are ſtrong. The lateſt and moſt probable opinion therefore is, that the drum of the ear is not ſo much deſigned to render us capable of hearing ſounds, (for we can hear without it) but to make us capable of exactly diſtinguiſhing them. To render us ſenſible of the difference between deep and ſhrill tones, or, as they are otherwiſe called, between ſounds that are grave, and ſuch as are acute. For the reception of a ſhrill tone the drum is braced tightly, and therefore vibrates with the ſwifteſt and ſhorteſt tremblings; in receiving the grave tones, it is braced more looſely, its tremblings therefore are free, wide, and open.

As a confirmation of this opinion, it is obvious, that thoſe who have the drum of the ear any way inflamed or diſordered, can bear to hear deep or grave ſounds; but the ſhrill and acute give them inexpreſſible pain. In order to prepare for the ſhrill ſound, the drum, as was ſaid, muſt be braced up tight, and this bracing will neceſſarily be as painful as it would be to ſtretch out a finger ſtreight that was contracted by an inflammation. However this be, the contrivance for the increaſe of ſound in the ear is allowed to be admirable by all. Human ingenuity can make a machine, which may imitate viſion exactly; but nothing that the art of man can form is found to increaſe ſounds ſo much in ſo ſmall a compaſs as the human ear.

Most ſounds, we all know, are conveyed to us on the boſom of the air. In whatever manner they either float upon it, or are propelled forward in it, certain it is, that without the vehicle of this or ſome other fluid, we ſhould have no ſounds at all. Let the air be exhauſted from a receiver, and a bell ſhall emit no ſound when rung in the void; for, as the air continues to grow leſs denſe, the ſound dies away in proportion, ſo that at laſt its ſtrongeſt vibrations are almoſt totally ſilent.

Thus air is a vehicle for ſound. However, we muſt not with ſome philoſophers aſſert, that it is the only vehicle; that if there were no air, we ſhould have no ſounds whatſoever: for it is found by trial, that ſounds are conveyed through water almoſt with the ſame facility with which they move through air: a bell rung in water returns a tone as diſtinct as if rung in our aerial atmoſphere. This was obſerved by Derham, who alſo remarked, that the tone came a quarter deeper. Natural hiſtorians aſſure us alſo, that fiſhes have a ſtrong perception of ſounds, even at the bottom of deep rivers. From hence, therefore, we may, I think, reaſonably infer, that it is not very material in the propagation of ſounds, whether the fluid which conveys them be elaſtic or otherwiſe. Water, which of all ſubſtances that we know, has the leaſt elaſticity, yet ſerves to carry them forward; and if we make allowance for the difference of its denſity, perhaps the ſounds move in it with a proportional rapidity, to what they are found to do in the elaſtic fluid of air. It may be ſaid, indeed, that the water conveys ſounds not of itſelf, but becauſe mixed with a quantity of air, which is not totally deprived of its elaſticity; that the ſound is carried forward by the vibrations of this. To this way of reaſoning we anſwer nothing: it may ſerve to fortify an hypotheſis well enough, but it will never carry conviction with it.

ONE thing however is certain, that whether the fluid which conveys the note be elaſtic or non-elaſtic, whatever ſound we hear is produced by a ſtroke, which the ſounding body makes againſt the fluid, whether air or water. The fluid being ſtruck upon, carries the impreſſion forward to the ear, and there produces its ſenſation. Philoſophers are ſo far agreed, that they all allow that ſound is nothing more than the impreſſion made by an elaſtic body upon the air or water, and this impreſſion carried along by either fluid to the organ of hearing. But the manner in which this conveyance is made is ſtill diſputed: Whether the ſound is diffuſed into the air, in circle beyond circle, like the waves of water, when we diſturb the ſmoothneſs of its ſurface by dropping in a ſtone, or whether it travels along, like rays

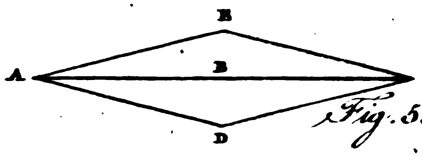

Fig. 53. p. 173

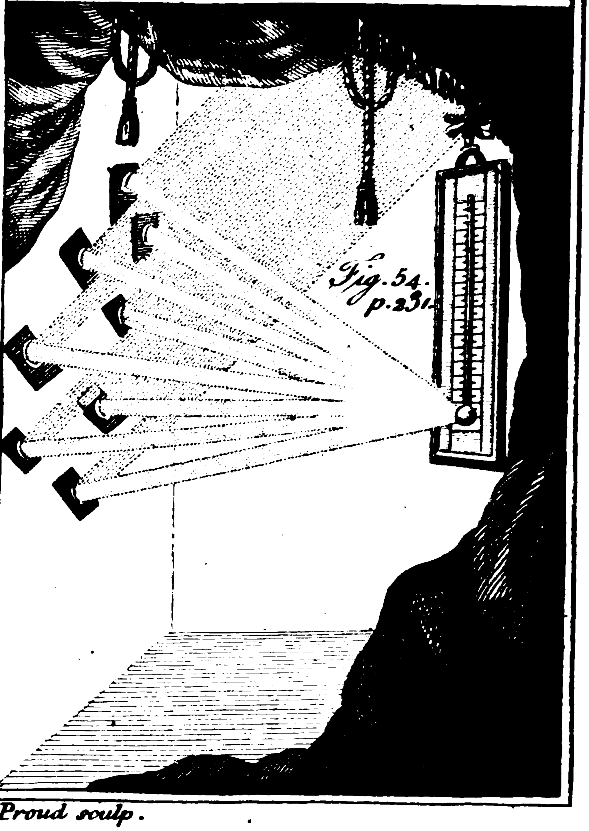

Fig. 54. p. 231.

Proud sculp.

rays diffuſed from a center, ſomewhat in the ſwift manner that electricity runs along a rod of iron; theſe are the queſtions which at preſent divide the learned, and are likely to continue to divide them.

NEWTON was of the firſt opinion. He has explained the progreſſion of ſound by an undulatory, or rather a vermicular motion in the parts of the air. If we have an exact idea of the crawling of ſome inſects, we ſhall have a tolerable notion of the progreſſion of ſound upon this hypotheſis. The inſect, for inſtance, in its motion firſt carries its contractions from the hinder part, in order to throw its fore part to the proper diſtance, then it carries its contractions from the fore part to the hinder, to bring that forward. Something ſimilar to this is the motion of the air when ſtruck upon by a ſounding body. To be a little more preciſe, ſuppoſe ABC, (ſee fig. 53.) the ſtring of an harpſichord ſcrewed to a proper pitch, and drawn out of the right line by the finger at B. We formerly ſaid, that ſuch a ſtring would, if let go, vibrate to E, and from E to D, and back again. We obſerved, that it would continue thus to vibrate like a pendulum for ever, if not externally reſiſted, and, like a pendulum, all its little vibrations would be performed in equal times, the laſt and the firſt being equally long in performing. We ſhewed alſo that, like a pendulum, its greateſt ſwiftneſs would always be when it arrived at E, the middle part of its motion. Now then, if this ſtring be ſuppoſed to fly from the finger at B, it is obvious, that whatever be its own motion, ſuch alſo will be the motion of the parts of air that fly before it. Its motion, as is obvious, is firſt uniformly accelerated forward from B to E, then retarded as it goes from E to D, accelerated back again as it returns from D to E, and retarded from E to B. This motion being therefore ſent in ſucceſſion through a range of elaſtic air, it muſt happen, that the parts of one range of air muſt be ſent forward with accelerated motion, and then with a retarded motion. This accelerated motion reaching the remoteſt end of the firſt range will be communicated to a ſecond range, while the neareſt parts of the firſt range being retarded in their motion, and falling back with the receſſion of the ſtring, retire firſt with an accelerated, then with a retarded motion, and the remoteſt parts will ſoon follow. In the mean time, while the parts of the firſt range are thus falling back, the parts of the ſecond range are going forward with an accelerated motion. Thus there will be an alternate condenſation and relaxation of the air, during the time of one vibration; and as the air going forward ſtrikes any oppoſing body with greater force than upon retiring, ſo each of theſe accelerated progreſſions have been called by Newton a pulſe of ſound.

THUS will the air be driven forward in the direction of the ſtring. But now we muſt obſerve, that theſe pulſes will move every way; for all motion impreſſed upon fluids in any direction whatſoever, operates all around in a ſphere: ſo that ſounds will be driven in all directions, backwards, forwards, upwards, downwards, and on every ſide. They will go on ſucceeding each other, one without ſide the other, like circles in diſturbed water; or rather, they will lie one without the other, in concentric ſhells, ſhell above ſhell, as we ſee in the coats of an onion.

ALL who have remarked the tone of a bell, while its ſounds are decaying away, muſt have an idea of the pulſes of ſound, which, according to Newton, are formed by the air's alternate progreſſion and receſſion. And it muſt be obſerved, that as each of theſe pulſes are formed by a ſingle vibration of the ſtring, they muſt be equal to each other; for the vibrations of the ſtring are known to be ſo.

Again, as to the velocity with which ſounds travel, this Newton determines, by the moſt difficult calculation that can be imagined, to be in proportion to the thickneſs of the parts of the air, and the diſtance of theſe parts from each other. From hence he goes on to prove, that each little part moves backward and forward like a pendulum; and from thence he proceeds to demonſtrate, that if the atmoſphere were of the ſame denſity every where as at the ſurface of the earth, in ſuch a caſe, a pendulum that reached from its higheſt ſurface down to the ſurface of the earth, would by its vibrations diſcover to us the proportion of the velocity with which ſounds travel. The velocity with which each pulſe would move, he ſhews, would be as much greater than the velocity of ſuch a pendulum ſwinging with one complete vibration, as the circumference of a circle is greater than the diameter. From hence he calculates, that the motion of ſound would be nine hundred and ſeventy-nine feet in one ſecond. But this not being conſonant to experience, he takes in another conſideration, which deſtroys entirely the rigour of his former demonſtration, namely, vapours in the air, and then finds the motion of ſound to be one thouſand one hundred and forty-two in one ſecond, or near thirteen miles in a minute: a proportion which experience had eſtabliſhed nearly before.

THUS much will ſerve to give an obſcure idea of a moſt obſcure theory: a theory which has met with numbers of oppoſers; ſome more forward, condemning what they thought they knew, but did not really underſtand; others more prudent, condemning the whole doctrine, not as falſe, but becauſe obſcure. Even John Bernouilli, Newton's greateſt diſciple, modeſtly owns that he did not pretend to underſtand this part of Newton's Principia. He attempted therefore to give a more perſpicuous demonſtration of his own, that might confirm and illuſtrate the Newtonian theory. The ſubject ſeemed to reject elucidation: his theory is obviouſly wrong, as D'Alembert has proved in his Theory of Fluids. Euler, therefore, rejecting the Newtonian doctrine entirely, has attempted to eſtabliſh another; but as he has hitherto only given the reſult of his calculations, without the progreſſive proofs that confirm his opinion, the learned continue in ſuſpenſe as to the merit of his work.

VARIOUS have been the objections that have been made to the Newtonian ſyſtem of ſounds. Firſt, it is urged, that if the firſt pulſe of ſound be driven by that which immediately follows, and that by the ſucceeding, and ſo on, it muſt then happen, that the more numerous the pulſes, the farther will the ſound be driven; ſo that a ſtring which vibrates the longeſt will be heard at the greateſt diſtance, which is contrary to known experience. Again, it is urged, that this theory can only agree with the motion of ſound in an elaſtic fluid, whereas ſounds are known to move forward through water that is not elaſtic: to explain their progreſs therefore through water, a ſecond theory muſt be formed: ſo that two theories muſt be made to explain a ſimilar effect, which is contrary to the ſimplicity of true philoſophy, for it is contrary to the ſimplicity of nature. It is ſtill farther urged, that this ſlow vermicular motion but ill repreſents the velocity with which ſounds travel, as we know by experience, that it is almoſt thirteen miles in a minute. In ſhort, it is urged, that ſuch undulations as have been deſcribed, when coming from ſeveral ſonorous bodies at once, would croſs, obſtruct, and confound each other; ſo that, if they were conveyed to the ear by this means, we ſhould hear nothing but a medley of diſcord, and broken articulations. But this is equally with the reſt contradictory to experience, ſince we hear the fulleſt concert, not only without confuſion, but with the higheſt pleaſure. Theſe objections, whether well founded or not, have given riſe to another theory. The reader muſt judge for himſelf, which of the two he will prefer: *non noſtrum eſt tantas componere lites.*

EVERY ſound may be conſidered as driven off from the ſounding body in ſtraight lines, and impreſſed upon the air in one direction only; but whatever impreſſion is made upon a fluid in one direction, is diffuſed upon its ſurface into all directions: ſo that the ſound firſt driven directly forward ſoon fills up a wide ſphere, and is heard on every ſide. Thus, as it is impreſſed, it inſtantaneouſly travels forward with a very ſwift motion, reſembling the velocity with which we know electricity flies from one end of a line to another.

Now, as to the pulſes, or open ſhakes, as the muſicians expreſs it, which a ſounding body is known to make, a little reflection may ſerve to ſhew, that each pulſe is itſelf a diſtinct and perfect ſound, and that the interval between every two pulſes is profoundly ſilent. Continuity of ſound from the ſame body is only a deception of the hearing; for as each diſtinct ſound ſucceeds at very ſmall intervals, the organ has not time to tranſmit its images with equal ſwiftneſs to the mind, and the interval is thus loſt to ſenſe: juſt as in ſeeing a flaming torch, if flared round in a circle, it appears as a ring of fire. In this manner a beaten drum, at ſome ſmall diſtance, preſents us with the idea of continuing ſound. When children run with their ſticks along a rail, a continuing ſound is thus repreſented, though it need ſcarce be obſerved, that the ſtrokes againſt each rail is perfectly diſtinct and inſulated.

According to this theory, therefore, the pulſes are nothing more than diſtinct ſounds repeated by the ſame body, the firſt ſtroke or vibration being ever the loudeſt, and travelling farther than thoſe that follow; while each ſucceeding vibration gives a new ſound, but with diminiſhed force, till at laſt the pulſes decay away totally, as the force decays that gives them exiſtence.

All bodies whatſoever that are ſtruck, return more or leſs a ſound; but ſome wanting elaſticity, give back a repetition of the ſound: the noiſe is at once begotten and dies; while other bodies, however, there are, which being more elaſtic, and whoſe parts are capable of vibration, give back a ſound, and repeat the ſame ſeveral times ſucceſſively. Theſe laſt are ſaid to have a tone; the others are not allowed to have any.

This tone of the elaſtic ſtring or bell is notwithſtanding nothing more than a ſimilar ſound to what the former bodies produced, but with the difference of being many times repeated, while their note is but ſingle. So that, if we would give the former bodies a tone, it will be neceſſary to make them repeat their ſound, by repeating our blows ſwiftly upon them. This will effectually give them a tone, and even an unmuſical inſtrument has often had a fine effect by its tone in our concerts.

LET us now go on then to ſuppoſe, that by ſwift and equably continued ſtrokes we give any non-elaſtic body its tone, it is very obvious, that no alterations will be made in this tone by the quickneſs of the ſtrokes, though repeated never ſo faſt. Theſe will only render the tone more equal and continuous, but make no alteration in the tone it gives. On the contrary, if we make an alteration in the force of each blow, a different tone will then undoubtedly be excited. The difference will be ſmall, I muſt confeſs, for the tones of theſe inflexible bodies are capable but of ſmall variation; however, there will certainly be a difference. The table on which I write, for inſtance, will return a different ſound when I ſtrike it with a club, from what it did when I only ſtruck it with a ſwitch. Thus non-elaſtic bodies return a difference of tone, not in proportion to the ſwiftneſs with which their ſound is repeated, but in proportion to the greatneſs of the blow which produced it; for in two equal non-elaſtic bodies, that body produced the deepeſt tone that was ſtruck by the greateſt blow.

We now then come to a critical queſtion, What is it that produces the difference of tone in two elaſtic ſounding bells or ſtrings? Or what makes one deep and the other ſhrill? This queſtion has always been hitherto anſwered by ſaying, that the depth or heighth of the note proceeded from the ſlowneſs and ſwiftneſs of the times of the vibrations. The ſloweſt vibrations, it has been ſaid, are qualified for producing the deepeſt tones, while the ſwifteſt vibrations produce the higheſt tones. In this caſe an effect has been given for a cauſe. It is in fact the force with which the ſounding ſtring ſtrikes the air when ſtruck upon, that makes the true diſtinction in the tones of ſounds. It is this force, with greater or leſs impreſſions, reſembling the greater or leſs force of the blows upon a non-elaſtic body, which produces correſpondent affections of ſound. The greateſt forces produce the deepeſt ſounds: the high notes are the effect of ſmall efforts. In the ſame manner a bell, wide at the mouth, gives a grave ſound; but if it be very maſſy withal, that will render it ſtill graver; but if maſſy, wide, and long or high, that will make the tone deepeſt of all.

THUS then will elaſtic bodies give the deepeſt ſound, in proportion to the force with which they ſtrike the air; but if we ſhould attempt to increaſe their force by giving them a ſtronger blow, this will be in vain: they will ſtill return the ſame tone; for ſuch is their formation, that they are ſonorous only, becauſe they are elaſtic, and the force of this elaſticity is not increaſed by our ſtrength, as the greatneſs of a pendulum's vibration will not be increaſed by falling from a greater height.

THUS far of the lengths of cords; now as to the frequency with which they vibrate the deepeſt tones, it has been found, from the nature of elaſtic ſtrings, that the longeſt ſtrings have the wideſt vibrations, and conſequently go backward and forward sloweſt; while, on the contrary, the ſhorteſt ſtrings vibrate the quickeſt, or come and go in the ſhorteſt intervals. From hence thoſe who have treated of ſounds have aſſerted, as was ſaid before, that the tone of the ſtring depended upon the length or the ſhortneſs of the vibrations. This, however, is not the caſe.

One and the ſame ſtring, when ſtruck, muſt always, like the ſame pendulum, return preciſely ſimilar vibrations; but it is well known, that one and the ſame ſtring, when ſtruck upon, does not always return preciſely the ſame tone: ſo that in this caſe the vibrations follow one rule, and the tone another. The vibrations muſt be invariably the ſame in the ſame ſtring, which does not return the ſame tone invariably, as is well known to muſicians in general. In the violin, for inſtance, they can eaſily alter the tone of the ſtring an octave or eight notes higher, by a ſofter method of drawing the bow; and ſome are known thus to bring out the moſt charming airs imaginable. Theſe peculiar tones are by the Engliſh fiddlers called Flute Notes, if I miſtake not. The only reaſon that can be aſſigned for the ſame ſtring thus returning different tones, muſt certainly be the different force of its ſtrokes upon the air. In one caſe, it has double the tone of the other, becauſe upon the ſoft touches of the bow, only half its elaſticity is put into vibration.

THIS being underſtood, we ſhall be able clearly to account for many things relating to ſounds that have hitherto been inexplicable. Thus, for inſtance, if it be aſked, When two ſtrings are ſtretched together of equal lengths, tenſion, and thickneſs, how does it happen, that one of them being ſtruck, and made to vibrate throughout, the other ſhall vibrate throughout alſo? The anſwer is obvious: the force that the ſtring ſtruck receives is communicated to the air, and the air communicates the ſame to the ſimilar ſtring, which therefore receives all the force of the former, and the force being equal, the vibrations muſt be ſo too. Again put the queſtion, If one ſtring be but half the length of the other, and be ſtruck, how will the vibrations be? The anſwer is, the longeſt ſtring will receive all the force of the ſtring half as long as itſelf, and therefore it will vibrate in proportion, that is, through half its length. In the ſame manner, if the longeſt ſtring were three times as long as the other, it would only vibrate in a third of its length: or if four times, in a fourth of its length. In ſhort, whatever force the ſmaller ſtring impreſſes upon the air, the air will impreſs a ſimilar force upon the longer ſtring, and partially excite its vibrations.

FROM hence alſo we may account for the cauſe of thoſe charming, melancholy gradations of ſound in the Eolian lyre, a modern inſtrument, invented by Mr. Oſwald. The Eolian lyre is eaſily made, being nothing more than a long narrow box of thin deal, about a yard long, and four inches wide, with an hole on one ſide. On this ſide are ſeven ſtrings of very fine gut, ſtretched over bridges at each end, like the bridge of a fiddle, and ſcrewed up or relaxed with ſcrew pins. The ſtrings are all tuned to one and the ſame note, and the inſtrument is placed in ſome current of air, where the wind can bruſh over its ſtrings with freedom. A window with the ſaſh juſt raiſed, to give the air admiſſion, will anſwer this purpoſe exactly. Now when the entering air blows upon theſe ſtrings with different degrees of force, there will be excited different tones of ſound; ſometimes the blaſt brings out all the tones in full concert; ſometimes it ſinks them to the ſofteſt murmurs; it feels for every tone, and by its gradations of ſtrength ſolicits thoſe gradations of ſound, which art has taken different methods to produce.

We come now, in the laſt place, to conſider the loudneſs and the lowneſs, or as muſicians ſpeak, the ſtrength and ſoftneſs of ſounds. In vibrating elaſtic ſtrings, the loudneſs of the tone is in proportion to the deepneſs of the note; that is, in two ſtrings, all things in other circumſtances alike, the deepeſt tone will be loudeſt. In muſical inſtruments, upon a different principle, as in the violin, it is otherwiſe; the tones are made in ſuch inſtruments, by a number of ſmall vibrations crowded into one ſtroke. The refined bow, for inſtance, being drawn along a ſtring, its roughneſſes catch the ſtring at very ſmall intervals, and excite its vibrations. In this inſtrument, therefore, to excite loud tones, the bow muſt be drawn quick, and this will produce the greateſt number of vibrations. But it muſt be obſerved, that the more quick the bow paſſes over the ſtring, the leſs apt will the roughneſs of its ſurface be to touch the ſtring at every inſtant; to remedy this, therefore, the bow muſt be preſſed the harder as it is drawn quicker, and thus its fulleſt ſound will be brought from the inſtrument. If the ſwiftneſs of the vibrations in an inſtrument thus rubbed upon, exceed the force of the deeper ſound in another, then the ſwift vibrations will be heard at a greater diſtance, and as much farther off, as the ſwiftneſs in them exceeds the force in the other.

But one thing more remains. It may be objected to this theory, that if the tone of a ſtring was cauſed by the force of its ſtroke, then thoſe parts of the air that were neareſt the ſounding body would be impreſſed with the greateſt force, and would therefore give the greateſt or deepeſt tone; while, as the ſound went off to a greater diſtance, and the force became conſequently leſs, the tone would become leſs alſo; or, in other words, grow higher and higher: but this, continue the objectors, is known, by experience, to be otherwiſe. To this it might be anſwered, that the force once impreſſed continues ever the ſame. But, in fact, I am apt to allow their objection, but to deny their concluſion. I am inclined to believe that the tone actually alters as it travels onward, becoming higher, as it recedes from the ſounding body. I would offer the following reaſons for this opinion, rather as motives to excite farther ſearch, than as deciſions to ſatisfy curioſity. In hearing diſtant ſounds, it is probable, we labour under the ſame continual deceptions which we do in ſeeing diſtant objects; the judgment in both is ever correcting the erroneous repreſentation of the ſenſes. A man, when ſeen at a mile's diſtance, appears actually but a few inches tall, yet the perſon who ſees him, would be ſurpriſed, if told, that what he ſaw was an object no bigger than his finger. It may be the ſame with ſounds; the tone may diminiſh by diſtance, and yet we may not be ſenſible of it without a nice compariſon. It may be added, that as viſual objects, when placed at a diſtance, fade from the ſight, and aſſume the colour of the air as they remove; ſo ſounds, to uſe the painter's word, may have their *keeping* in like manner, and thus by becoming indiſtinct and low.

THAT we labour under a deception with regard to tones, and that they become higher as they come from a greater diſtance, may be inferred from muſical compoſition. The greateſt maſters in this art, when they would imitate a diſtant echo, generally take the ſounds an octave higher. A few years ago, a fellow exhibited in Weſtminſter, the art of imitating ſounds at any diſtance whatever. I remarked, that whenever he deſigned to imitate a voice coming from a great diſtance, he not only made the ſound more low and indiſtinct, but raiſed the tone ſeveral pitches higher than that uſed in his nearer imitations. A few obſervations ſince made upon ſounds, induce me to believe, that they become higher as they come from a diſtance more remote; while, on the contrary, that they deepen, the more the vibrations approach the labyrinth of the ear. The following eaſy and common experiment I think will prove it. Take any thing whatever, capable of giving a ſound; let it be a common poker, for inſtance; and tying on a garter at top, ſo as that both ends of the garter are left at liberty; theſe ends muſt be rolled round the firſt finger of each hand, and then with theſe fingers ſtopping the ears cloſe, ſtrike the poker, thus ſuſpended, againſt any body whatſoever. The depth of the tone which this new muſical inſtrument returns will be amazing. The deepeſt and largeſt bell will not equal it. Whence is this, unleſs from the cloſe approach of the ſounding body, whoſe vibrations are immediately communicated to the internal parts of the ear. I am ſenſible that many objections may be made to this laſt opinion; ſucceeding experience muſt, however, determine whether it be juſt or not: but ſuch as make them muſt be particularly careful, not to let their former experience correct their immediate ſenſations. This alteration of tone, with diſtance, however, muſt diminiſh but by great intervals. The firſt part of this theory appears to me very probable, whatever befalls the latter part of it. Some of the outlines are taken from ſome hints dropped by Mr. Buffon.

HOWEVER it may be with regard to the theories of ſound, experience has taught us, that it travels at about the rate of 1142 feet in a ſecond, or near thirteen miles in a minute. The method of calculating its progreſs is eaſily made known. When a gun is diſcharged at a diſtance, we ſee the fire long before we hear the ſound. If then we know the diſtance of the place, and know the time of the interval between our firſt ſeeing the fire and then hearing the report, this will ſhew us exactly the time the ſound has been travelling to us. For inſtance, if the gun is diſcharged a mile off, the moment the flaſh is ſeen, I take a watch and count the ſeconds till I hear the ſound; the number of ſeconds is the time the ſound has been travelling a mile.

DERHAM has gone yet farther, and proved by experience, that all ſounds whatever travel at the ſame rate. The ſound of a gun, and the ſtriking of a hammer, are equally ſwift in their motions; the ſofteſt whiſper flies as ſwiftly, as far as it goes, as the loudeſt thunder.

As ſound is communicated from a ſingle point, in every direction, it muſt, of conſequence, diminiſh in ſtrength the farther it goes. All bodies ſent out directly in rays from a center, meet greater reſiſtances, as the ſquares of their diſtances become greater; and therefore the progreſs of ſounds will be reſiſted in proportion, as their diſtances, by being ſquared, increaſe.

THIS, however, muſt not be conſidered as a conſtant rule; for when a ſound travels againſt the wind, it takes a longer time than when it flies before it. Of conſequence it goes faſter one way than the other, and thus, as it is no longer diffuſed in a ſphere, the law of its progreſs forward muſt alſo be altered. Ulloa thinks that the ſame ſound which, againſt a ſtrong wind, travels nine miles and a half, would, if it went with the wind in the ſame time, travel ten miles and a half, that is a whole mile farther.

To drive the human voice to the greateſt diſtance, we are obliged to make uſe of art. The inſtrument called the ſpeaking trumpet is well known at land; but it is indiſpenſably neceſſary at ſea. The voice reflected from the ſides of this tube, which is made pretty much in the figure of an huntſman's ſtraight horn, is encreaſed at its mouth, and thus, as it is ſaid, ſtrikes the air with greater force. There are very different opinions, both with reſpect to the manner in which the ſpeaking trumpet increaſes ſound, and alſo with regard to the beſt figure of ſuch an inſtrument; the logarithmic curve has been adopted by ſome, and the parabolic curve by others; it is for geometricians to diſpute; artiſts uſually chuſe a figure peculiar to themſelves.

A ſubject not leſs diſputed than the former, and ſtill leſs underſtood, is the cauſe and nature of an echo. It is ſaid, in general terms, that an echo is a reflection of ſound, ſtriking againſt ſome object, as an image is reflected in a glaſs. If this, however, were the caſe, all bodies with a ſmooth ſurface would be capable of reflecting ſounds, which we know, by experience, they are not. That the ſound is reflected none can deny, the great difficulty lies in determining what are the proper qualities in a body for thus reflecting ſounds. Were this preciſely known, we ſhould then be able to make an echo at pleaſure; but ſome have found, to their coſt, that ſuch an attempt is impracticable; whatever arts they have tried to bring the coy nymph to their gardens or pleaſure-houſes, have proved ineffectual; a poet would ſay, that ſhe flies the palaces of the great, content with ſolitude and privacy.

It is in general known, that caverns, grottoes, mountains, and ruined buildings return this image of ſound. Image we may call it, for in every reſpect it reſembles the image of a viſible object reflected from a poliſhed ſurface. Our figures are often repreſented in a mirrour, without ſeeing them ourſelves, while thoſe ſtanding on one ſide are alone ſenſible of the reflection. To be capable of ſeeing the reflected image of ourſelves, we muſt be directly in a line with the image. Juſt ſo is it in an echo; we muſt ſtand in the line in which the ſound is reflected, or the repetition will be loſt to us, while it may, at the ſame time, be diſtinctly heard by others who ſtand at a ſmall diſtance to one ſide of us. I remember a very extraordinary echo, at a ruined fortreſs near Louvain, in Flanders. If a perſon ſung, he only heard his own voice, without any repetition, on the contrary, thoſe who ſtood at ſome diſtance, heard the echo but not the voice; but then they heard it with ſurpriſing variations, ſometimes louder, ſometimes ſofter, now more near, then more diſtant. There is an account in the memoirs of the French academy, of a ſimilar echo near Rouen. The building which returns it is a ſemicircular court-yard; yet all buildings of the ſame form do not produce the ſame effects. We find ſome muſic halls excellently adapted for ſounds, while others, built upon the ſame plan, in a different place, are found to mix the tones, inſtead of enlarging them, in a very diſagreeable manner.

As we know the diſtance of places by the length of time a ſound takes to travel from them, ſo we may judge of the diſtance of an echo, by the length of the interval between our voice and its repetition. The moſt deliberate echoes, as they are called, are ever the moſt diſtant; while on the contrary, thoſe that are very near, return their ſounds ſo very quick as to have the interval almoſt imperceptible; when this is the caſe, and the echo is ſo very near, the voice is ſaid to be increaſed and not echoed; however, in fact, the increaſe is only made by the ſwiftly purſuing repetition. Our theatres and concert rooms are beſt fitted for muſic or ſpeaking, when they enlarge the ſound to the greateſt pitch, at the ſmalleſt interval: for a repetition which does not begin the word till the ſpeaker has finiſhed it, throws all the ſounds into confuſion. Thus the theatre at the Haymarket, enlarges the ſound very much; but then, at a long interval, after the ſinger or ſpeaker. The theatre at Drury-lane, before it was altered, enlarged the ſound but in a ſmall degree; but then the repetition was extremely quick in its purſuit; and the ſounds, when heard, were therefore heard diſtinctly. Dergoliſe, the great muſical compoſer, uſed to ſay, that an echo was the beſt ſchool-miſtreſs; for let a man's own muſic be never ſo good, by playing to an echo ſhe would teach him to improve it.

CHAP. XI.

Of ſome anomalous Properties of the Air, which have not been yet accounted for.

BESIDE theſe properties of the air, there are ſeveral others the cauſes of which are more obſcure, or to ſpeak more ingenuouſly, the cauſes of which we are not able to aſſign with ſo ſtrong an appearance of truth. Boyle has given us a chapter expreſsly upon this ſubject; where like a true philoſopher he confeſſes the limits of his own powers, and where he cannot find the true cauſes, refuſes to give conjectural ones. The vital principle of the air is one of its properties which cannot be accounted for, and which foil human ſagacity: that principle which it is poſſeſſed of in feeding flame, is alſo equally inſcrutable; it is driven off by heat, yet ſtill more ſtrange, heat cannot be continued without it.

The power it has of whitening ſome bodies and tanning others, is a property we may admire, but cannot account for. We are at a loſs alſo to account for the aptitude of the air, in keeping heterogeneous bodies ſupported on its boſom, while the heavier fluids of the ſame region and the ſame place are quite free from thoſe ſubſtances. Thus it is often found, that the air of ſome countries is extremely unhealthful and noxious, while the waters of the ſame place are admired for their ſalubrity. We have a ſhort memoir of one of the members of the Academy of Sciences in Paris to this purpoſe; "A maſon working by the ſide of a deep well near the city of Rennes, happening to let his hammer fall, one of the labourers who attended him, went down, but was ſuffocated before he reached the bottom: the ſame thing befel a ſecond, who went down to draw up the body; a third alſo underwent the ſame fate: a fourth, almoſt drunk, was let down, but with poſitive aſſurances to be drawn up the moment he gave the ſignal; this he quickly gave, but was drawn up ſenſeleſs, and died in three days after. The moſt extraordinary circumſtance of the relation is, that the water of this well had long been uſed by the neighbourhood without any noxious effects whatſoever.

ANOTHER of the air's inſcrutable qualities is, that if kept for ſome time incloſed in a veſſel without any communication with the external atmoſphere, it becomes deadly and peſtilential in the higheſt degree; all animals that are obliged to reſpire in it inſtantly die. We have another account of the peſtilential effects of cloſe air, related in the ſame work: " A baker of Chartres had a cellar under his houſe, to which there was a deſcent by a ſtaircaſe of thirty-ſix ſteps. Thither his ſon, a ſtrong young man, went to carry down a ſack of bran, but while he was on the ſteps the candle was extinguiſhed. Unconcerned at this, which he regarded as an accident, he went back, lighted his candle, and again returned; but as ſoon as he came to the loweſt ſtep he cried out, that he was unable—death interrupted the exclamation. His brother, a youth as remarkable for ſtrength as the former, inſtantly ran down to his aſſiſtance; but ſoon cried out that he was dying, and his cries ceaſed a few moments after. His wife went to his reſcue, a ſervant maid followed her, they were all ſuffocated. This accident terrified the whole village, and the inhabitants fled from the houſe with precipitation. At length one more reſolute than the reſt, being perſuaded that they were not yet dead, went down to aſſiſt them, but he was ſoon a ſharer in their fate. Not daunted at this, the next day a friend of the baker's was let down into the cellar by a cord; upon his crying out they attempted to draw him up again, but the cord breaking, he fell into the cellar and was ſuffocated inſtantly."

THE blood veſſels of the brain upon diſſection appeared diſtended, and the bowels inflamed. Upon throwing in a large quantity of water into the cellar theſe noxious effects were diſperſed, and a candle having been let down was drawn up without being put out, a certain indication of the melioration of the air.

ANOTHER property of the air, which has not yet been accounted for, is, that globular figure its parts aſſume, when the air, by means of the pump, or by fire, is forced out of the ſubſtances into which it has inſinuated. The bubbles in this caſe are always round; and though the bubble happens to ſwell to a thouſand times its former dimenſions, yet its globular figure ſtill remains. Can the parts of air of which theſe globules are compoſed be round themſelves? Or will any number of globes by being in contact one with the other, compoſe a figure that is round?

BUT of all the inſcrutable properties of the air, that by which it conveys ſounds from one place to another, is at preſent eſteemed the moſt obſcure: in the laſt age, when a philoſopher would bluſh if he could not be thought to aſſign a ready cauſe for every effect in nature, we then had theories of the progreſſion of ſound through an elaſtic fluid, and ſuch were generally embraced by the learned. Theſe theories, it muſt be owned, though they added nothing to a ſcholar's former fund of learning, yet ſerved to conceal the bounds of what he knew; for an obſcure anſwer will always ſatisfy the demands of inquiſitive ignorance, and create its eſteem: however, the doctrine of ſounds is now acknowledged the moſt obſcure part of natural philoſophy. The reaſon may be eaſily aſſigned. Newton attempted it without ſucceſs; and ſucceeding philoſophers have not had talents equal to the elucidation of what he left obſcure. The two minims, Le Sueur and Jacquier, who commented upon his *Principia*, have proved the Newtonian hypotheſis, relating to the motion of the particles of an elaſtic medium, to be fallacious, and have propoſed other methods for reſtoring the Newtonian doctrine of ſound; but neither have their explanations carried univerſal conviction; a preſumptive proof of their weakneſs or obſcurity.

A
SURVEY
OF
EXPERIMENTAL
PHILOSOPHY.

BOOK III.

CHAPTER I.

OF FIRE.

Ignis ubique latet, naturam amplectitur omnem,
Cuncta parit, renovat, dividit, urit, alit.

THESE are the properties of Fire as enumerated by a modern wit; and nothing can be at once more full and more conciſe. All things contain Fire, ſays he, in ſome degree; it produces, it renews, divides, conſumes, or nouriſhes every part of Nature: every perſon's experience muſt inform him of the obvious properties of Fire; and in fact, philoſophers more readily prove its exiſtence, than give its definition.

WHAT is Fire? This is a queſtion which has divided the greateſt men, as well among the ancients as moderns: of the latter, Boerhaave, Homberg, and Lemery, ſuppoſe fire to be a body actually exiſting, like air, water, or any other fluid, and diffuſed through all nature. It is to be found, ſay they, in all places and in all things, only wanting to be collected into a narrow compaſs, in order to become manifeſt to the ſenſes. They ſay, that, upon uniting with other bodies, it not only increaſes their bulk, but their weight alſo. That it ſometimes is collected in ſuch a manner, that ſome of its properties only appear, as when it ſhines without burning: at other times different properties are collected, and it burns without ſhining, as in metals heated to a certain pitch.

To theſe chymical philoſophers are oppoſed no leſs names than Bacon, Boyle, and Newton: theſe deny that fire is by any means itſelf a body, but only ariſes from the attrition or rubbing of bodies one againſt the other. Charcoal ignited, ſay they, what is it but wood made red and burning? A bar of iron hiſſing from the forge, what is it but iron ſtill? In ſhort, ſay they, wherever a violent attrition or inteſtine motion of the parts can be excited between bodies, fire will be the neceſſary reſult; ſuch bodies will ſometimes caſt forth flame, and flame is itſelf nothing more than parts exceſſively ſmall, put violently into motion.

MODERN philoſophers in general incline to the opinion of Boerhaave, and concur with the ancients in affirming, that fire is an element of a peculiar kind and an inſcrutable nature, with properties peculiar to itſelf, every where appearing, but no where certainly known. Let us leave therefore the nature of this element to thoſe who love diſputation, and give the moſt obvious properties of fire, but without attempting in the leaſt to inveſtigate their cauſe.

THE moſt conſtant property of fire is its heat: heat is ever found to increaſe the bulk of all bodies before it begins to conſume them. When heat is applied to any ſubſtance, to iron for inſtance, in a moderate degree it ſwells; the ſame heat increaſed ſtill, increaſes all its dimenſions. As long as the heat or fire is continued, the dilatation increaſes, and the more ardent the one becomes, the more bulky ſtill will be the other. The dilatation, however, of the ſubſtance has its bounds, nor can it be infinitely increaſed. When the fire is firſt applied, the dilatation begins ſlowly; it then accelerates till it comes to a certain pitch, then it goes on ſlowly again; but at laſt, though the fire be never ſo ardent, or continued never ſo long, the dilatation is at a ſtand. If we would deſire to know exactly in what proportion bodies of different hardneſs or different weights dilate; this neither theory nor experience can reſolve. Some very hard bodies dilate more than others leſs hard; but then ſome bodies harder ſtill, dilate leſs than either. Tin dilates ſooner than the ſofter body, lead; iron, harder than tin, dilates leſs than either of them.

Of all fluids which are dilated by heat, air is the moſt eaſily expanded: next to that the chymical æther, then ſpirit of wine, then the oil called petroleum, then oil of turpentine, rape oil, diſtilled vinegar, freſh water, ſalt water, ſpirit of vitriol, ſpirit of nitre, and quickſilver, IN order to meaſure this expanſion of bodies, as well by fire as by a more moderate heat, two inſtruments have been contrived; namely, the pyrometer, and the thermometer: the pyrometer ſerves to ſhew the degrees of heat in ſolid bodies, the thermometer in fluids; the pyrometer is uſually nothing more than a rod of metal equally heated and ſo fixed, that as the heat increaſes, its minuteſt dilatations may be diſcovered by a nice adjuſted ſcale. Several methods of making them have been propoſed; all the methods are equally good, as the inſtrument at beſt can anſwer but few purpoſes of either ſpeculation or utility.

THE thermometer is an inſtrument much more known, and infinitely more uſeful; it very preciſely meaſures the degree of heat in all fluids, and conſequently informs us of the temperature of the air. This inſtrument ſhews exactly when the weather is hot and when it is cold, which, whatever we may boaſt of our natural ſenſations, they but very imperfectly diſcover. A man, for inſtance, going into a warm apartment of a bagnio, finds the air of the room exceſſively warm; but after being for ſome time in the bath, which is ſtill hotter, if he then comes out into the ſame apartment, though the air ſtill continues the ſame, he ſhall think it exceſſively cold. The travellers who go up the Andes, which are the higheſt mountains in the world, often meet other travellers coming down, who have been in the province of Quito, which lies near its top. Their ſenſations are very different, as Ulloa informs us. The deſcending traveller, who has left the cold country above, is almoſt ſtifled with heat; the traveller, who aſcends from the torrid regions below, freezes with cold; the one throws off his garment, and the other ſeizes it with haſte to keep himſelf warm. As our natural feelings are thus incapable of diſtinguiſhing the real warmth of the air, or any other ſubſtances, the thermometer is called in, which anſwers the end with much greater preciſion. This inſtrument is nothing more than a fluid incloſed in a glaſs tube nicely marked, and as the fluid ſwells with heat, it fills more of the tube, and conſequently riſes higher; on the contrary, as it contracts with cold, it ſinks in the tube; and thus riſing or falling, meaſures the true temperature of the weather, or the degree of heat in any fluid into which it is immerſed. The thermometer was firſt diſcovered by one Drebbel, a common Dutch peaſant, who uſed it merely to direct him in his occupations of huſbandry. Philoſophers ſoon found the uſe of ſuch an inſtrument, improved and converted it to purpoſes far beyond what the inventor had any idea of. The thermometer now uſed moſt frequently, is that of Fahrenheit's improvement. The fluid with which the bulb at the bottom is filled, is mercury; upon the ſide of the tube are marked the diviſions at which the fluid expands by different degrees of heat from freezing, which he calls the freezing point, up to the greateſt heats fluid ſubſtances are capable of receiving. Thus when we ſay, human heat is ninety-eight degrees by Fahrenheit's thermometer, it means only this, that the heat of a man's body is ninety-eight of thoſe degrees warmer than water when it begins to freeze. On the other hand, when we are told, that in Greenland the mercury ſometimes ſtands ſeven degrees lower than 0 by Fahrenheit's thermometer, it only implies that the air is ſeven degrees colder than water when it begins to freeze. Several other kinds of thermometers have been made uſe of by different naturaliſts; the difference in any of them is not very material, it is only proper that they ſhould hold to ſome one ſtandard, otherwiſe when a philoſopher tells us, that the air is at ſuch a time thirty degrees of his thermometer, we can have no idea of its peculiar heat, unleſs we have a draught of his peculiar inſtrument alſo. Newton's thermometer meaſured the degrees of heat with oil inſtead of mercury; perhaps ſuch an inſtrument is more juſt, but it is by no means ſo portable as the former.

PHILOSOPHERS having thus agreed upon inſtruments that can preciſely meaſure the degrees of heat and cold, can underſtand each other, when they talk of the different dilatations in bodies, with preciſion.

BUT heat does not only increaſe the bulk of bodies, but increaſes their weight alſo. A body weighed nicely before it is put into the fire, and then weighed again, will be found to be increaſed in weight very ſenſibly. It is remarkable enough, that lead when melted and redduced by heat to a red powder, receives a conſiderable addition to its weight from the operation of the fire, even after it is become cold again: a pound of lead by being thus reduced by heat, ſhall weigh ſeveral grains heavier than before.

It is not however the property of fire always to heat or expand thoſe bodies in which it reſides, for we frequently ſee it emitting light while it is perfectly cold. Phoſphorus, which ſhines in the dark, rotten wood, ſeveral kinds of fiſh, or fleſh as it begins to putrefy, and ſeveral other ſubſtances, all emit a light ſenſibly. So that light and heat may be conſidered as two ſocial qualities which are propagated from the ſame ſource, namely, from fire; but though uſually together, yet by ſome unknown means are often found diſunited.

Hot water cools ſooner by being placed under the exhauſted receiver of an air pump, while on the contrary iron cools ſooner in the open air. Shining rotten wood loſes all its light in the void, and never recovers it again; on the other hand, the glow-worm loſes its light, but ſoon recovers it again in the open air. If ſeveral bodies of different heats are all placed in the ſame cloſe apartment, after a ſhort time the heat will be equally diffuſed among them, and the thermometer will ſhew the degrees to be the ſame in all. Bodies heat by being expoſed to the air, but never if their moiſture be dried away. Hay when moiſt will take fire of itſelf, when dried it remains ſecure.

WOOD rubbed very ſwift with a circular motion takes fire. Several liquors poured one upon the other, though cold before, immediately take fire; ſuch as any acid, a ſpirit of vitriol for inſtance, when mixed with any eſſential oil, as oil of cloves. A flint ſtruck againſt a ſteel emits ſparks of fire, the ſulphur contained in the flint heating and melting the metal of the iron, and mixing with it and falling in ſmall drops, which may be gathered upon paper, and attracted by the loadſtone. But a property ſtill more extraordinary than any hitherto mentioned is, that theſe ſparks ſhall ſet fire to gunpowder, and the flame of a candle will not. In ſeveral mines in different parts of England, they are obliged to have very different kinds of light to carry on their work by. The flame of a candle in ſome mines would ſet their whole works on fire: they are therefore obliged to have a wheel with flints ſet round the circumference like the cogs of a mill wheel; theſe flints continually ſtriking a ſteel properly diſpoſed give a light, which ſerves to guide the operations of the workmen. Yet though ſuch a machine be requiſite in ſome places, a ſingle ſpark ſtruck between flint and ſteel would inſtantly fire other mines where they work by the light of flame, and be more fatal than the exploſion of tons of gunpowder: theſe are all properties of this element, for which we can aſſign no reaſon that impreſſes the ſmalleſt conviction.

There ſeem to be two ſources of fire by which all nature is refreſhed, aſſiſted, and even animated; for philoſophers now begin to allow, that animals may be produced from no other parent than heat alone. There are probably, I ſay, two ſources of fire, the central, or that heat which is contained deep in the bowels of the earth, and the ſolar, or ſun's heat. In digging mines or wells it is obſerved, that at a ſmall diſtance below the ſurface of the earth, the air feels a little chill; ſomewhat deeper it is colder, and when the workmen have come preciſely to that depth, beyond which the rays of the ſun cannot penetrate, water is found to freeze: when they deſcend ſtill more deep to about fifty feet below the ſurface, they then begin to perceive the place a little warmer and ice melts. The deeper they deſcend from this point, the more does the heat increaſe, until at length their breathing becomes difficult and their candles go out.

By this central heat many have explained earthquakes, the production of gems, minerals, and even the nutrition of vegetables. They who are moſt wedded to the ſyſtem, regard this heat as a central ſun, enlivening and refreſhing nature beneath the ſurface of the earth, as the planetary ſun does the external parts of the ſyſtem. Boyle, however, aſcribes the increaſe of heat at the loweſt depths to vapours, which mixing with others of a different and oppoſite nature, produce heat and ſometimes flame, as we ſee ſulphur when kneaded into a paſte with filings of iron frequently does.

The ſun, as we all experience, is the cauſe of heat, at the ſurface of the earth: whatever regions are ſtruck by its rays moſt perpendicularly, feel the influence of its heat with greateſt violence. For every object, placed directly beneath the rays, receive them in greateſt quantity; and beſides, every object that receives the perpendicular ray, will alſo receive the reflected rays, which will not be the caſe, if they fall obliquely; a material conſideration, though not uſually taken notice of. This heat of the ſun, which is ſo great at the ſurface of the earth, is much diminiſhed as we aſcend above it; ſo that the tops of mountains are generally extremely cold; and though ſome of them are internally fraught with fire, yet externally they are covered with ſnow. The mountain of Hecla, in Iceland, ſometimes caſts forth flames and earth melted like glaſs into a flaming torrent; this runs down its ſides in rivers, while the collected ſnow drives before the current, and the whole makes the moſt hideous cataract in nature. The cauſe of mountains being thus more cold than the valley below, is obvious; the valley reflects all the rays of the ſun, warms the air, and drives the rays back directly againſt the obſerver: the mountain reflects its rays in a ſmaller quantity; the air is thin, and will not admit of much warmth, and the obſerver is more out of the line of each reflected ray.

Of all bodies which reflect or throw back the rays of the ſun, thoſe which are ſmooth, well poliſhed, and but little porous, do it moſt powerfully; while, on the contrary, ſoft, ſpongy, porous bodies, reflect back but a few rays in compariſon, but, in a manner, ſuck them up and keep them within themſelves. A looking glaſs will throw back the rays that fall upon it very powerfully, with light and warmth, while a pillow ſhall ſcarce reflect any rays whatſoever. Of all ſubſtances however, poliſhed ſteel reflects the rays moſt, while, on the contrary, wool has the ſmalleſt power of reflection, tranſmitting the rays, and ſuffering them to paſs through its ſubſtance in the greateſt number. And for this reaſon, wool that thus imbibes the rays in ſuch great quantities muſt neceſſarily be warmer than any other ſubſtance; though Reaumur, in hatching chickens by the means of an oven alone, made uſe of an artificial hen made of wool to clutch the young brood when it came from the ſhell.

ALL bodies thus feel the influence of the ſun's rays, in proportion as they ſtrike againſt them more directly, or as the bodies are fitted for their reception. The rays, however, as they ever continue to operate, are, at the ſame time, reſtrained from burning too fiercely, by the nature and diſpoſition of the bodies upon which they fall; the heat is diffuſed evenly through their parts; and never in the natural ſtate of things, is it found to ſet the body in flames. To give the rays greater power they muſt be collected by art; and when their heat thus becomes united, they conſume, or, at leaſt, change all bodies whatſoever with inexpreſſible force. The hardeſt metals, ſteel itſelf melts, in a few minutes, into glaſs, and ſeems, by the violence of the heat, to loſe its nature;

in a few minutes more, the metal begins to ſend up fumes, and, at laſt, is totally evaporated away, to mix with the air in which we breathe.

To give an idea of the manner in which the ſun's rays are thus collected together, take ſix or eight ſmall looking-glaſſes, and holding them oppoſite to the ſun, let their reflected light fall all upon one ſpot, upon the crown of a hat for inſtance; if we put our hand there, we ſhall find the place much warmer than the ſun would have heated it without the reflection. If we make the united reflections fall upon the ball, at the bottom of the thermometer, (ſee fig. 54) we ſhall then be perfectly convinced of the increaſed heat by the riſing of the fluid in the tube. This experiment is eaſily tried, and the effects will always anſwer. Now, if inſtead of eight glaſſes we ſhould uſe a much greater number, the heat will be augmented in proportion, in the body upon which their united reflection falls. We have often ſaid, that all circles may be conſidered as compoſed of a number of right lines; and ſpherical figures may be conſidered as compoſed of a number of plain ſurfaces. Inſtead, therefore, of a number of plain glaſſes, if we ſhould make uſe of one concave mirrour, (ſee fig. 55) ſomewhat reſembling, in ſhape, the internal ſurface of a pewter baſon, this will throw the rays upon one point, and the body, which is placed exactly there, will be conſumed in a time proportioned to the mirrour's ſize and conſtruction. I am ſenſible that mentioning ſo vulgar an utenſil as a baſon, may incur ridicule; however, a very tolerable burning reflector may be made from one of theſe, newly taken out of the ſhop. For if a copper baſon or diſh formed of a true ſpherical figure, as ſome of them are, be well tinned on the inſide. If then quickſilver be put into this veſſel, and rolled about its ſides, it will unite with the tin, and ſtick to its ſurface

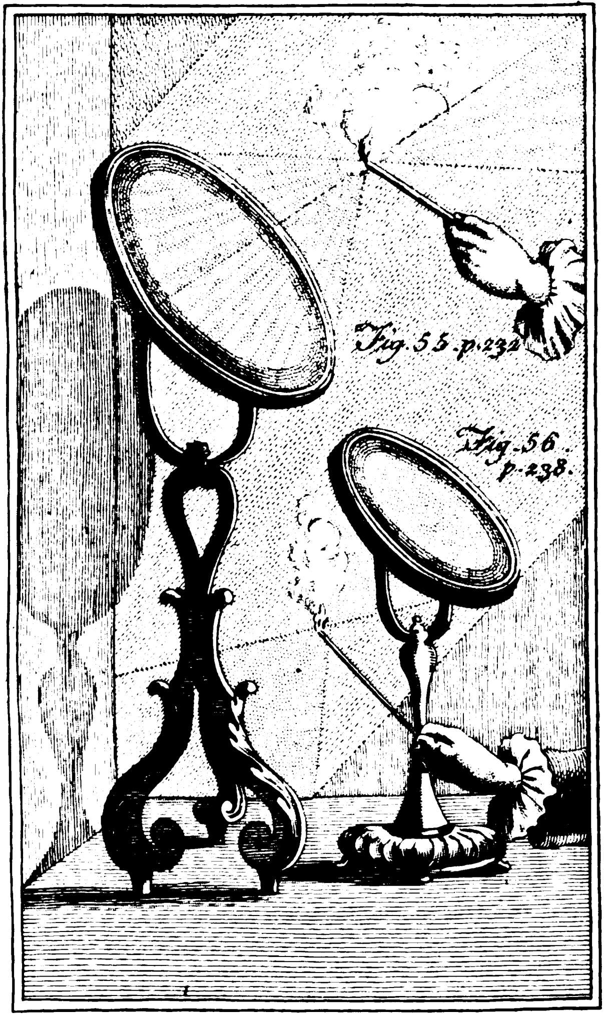
Fig.55.p.232
Fig.56.
p.238.

Proud sculp.

as water would, and ſilver the whole ſurface over with as fine a poliſh as it aſſumes behind a plate of looking-glaſs, for that is only quickſilver and tin mixed together, as in this experiment. The baſon thus poliſhed on the inſide will make a very good burning mirrour, and will conſume the denſeſt bodies, if laid in the proper point where the reflected rays unite together. Such a reflector is only for thoſe who will not be at the expence of ſuch as are more powerful. The beſt are thought to be thoſe made of poliſhed ſteel, as this metal is hardeſt and beſt reflects the rays. Others recommend a compoſition of tin and antimony; in ſhort, each philoſopher chuſes the materials of his mirrour; and thoſe, in general, are found to anſwer beſt, where the ſubſtance of which they are made is compact, bears an high poliſh, and is of a white colour; for it muſt be obſerved, that ſuch as are made of black materials, as of black marble, do not reflect the rays at all, or, at leaſt, but very feebly; for black is a quality which rather imbibes than reflects the rays that fall upon its ſurface. We have ſeveral accounts of the force with which concave mirrours, properly formed, deſtroy all ſubſtances put into the focus of their energy, for ſo is the point called, where all the reflected rays unite and burn fierceſt. The mirrour of Septala burnt at fifteen feet diſtance: Boerhaave ſays much of that made by Tſchirnhauſen. That of Villet's conſtruction is equally admired; it was near four feet in diameter, and burnt ſubſtances at a diſtance of three feet two inches with extreme violence. Iron ore placed in its eye or focus, melted in twenty-four ſeconds, bone was turned to glaſs in thirty-three ſeconds, a copper halfpenny had an hole melted through it in thirty ſeconds, and ſeveral other ſubſtances were conſumed with equal rapidity. Boerhaave informs us, that with his mirrour he has frequently turned gold to glaſs, but could never diminiſh its weight; others, however, aſſert the contrary, affirming that part of the gold is driven away, and a part remains behind, reduced, in a manner, to aſhes, or, as the chymiſts call it, to a *calx* or *caput mortuum*. Such are the effects of mirrours of this conſtruction; though it may be obſerved, however, that whatever metals are thus turned to glaſs or to aſhes by the effects of heat, may be reſtored to their natural ſtate by being united with charcoal, and ſo melted over again.

BUT whatever we are told of the effects of Villet's burning mirrour, they fall far ſhort of what has been performed by a mirrour more lately made by Mr. Buffon; for this burns at a diſtance of no leſs than two hundred feet. This excellent naturaliſt juſtly conſidered, that if a plain looking-glaſs warmed at a great diſtance, a number of plain glaſſes, united to fall their rays upon the ſame ſpot, would actually burn; he therefore put together ſeveral plain glaſſes, each about half a foot ſquare, and ſo diſpoſed as to have all their reflections fall upon one object, pretty much in the manner repreſented above. They are fixed in a frame which can alter their focal diſtance at pleaſure, ſo that the ſame machine which throws the combined reflected rays to a diſtance of two hundred feet, may, by the turn of an handle, be made to throw their united force upon an object not diſtant above twenty. It is remarkable enough, that Tzetzes, a Greek writer of the twelfth century, giving a a deſcription of the manner in which Archimedes burnt the fleet of the Romans, aſſures us it was in the manner we have juſt deſcribed. Archimedes, he ſays, made a number of plain mirrours with combined force, collect the rays of the ſun upon the veſſels in the harbour, and thus he ſet them on fire. The mirrours of the ancient mathematician, however, muſt have been much more powerful than thoſe of the modern naturaliſt; for Diodorus Siculus tells us, that Archimedes burnt the Roman fleet about three furlongs removed from ſhore. The moderns cannot conceive the manner in which this could be done, at ſo very remote a diſtance; ſo what they cannot underſtand they boldly deny; and aſſure each other, that Archimedes never burnt the Roman fleet.

POLISHED ſubſtances reflect the rays in greateſt abundance; but no ſubſtance whatſoever is wholly deſtitute of this reflecting power. In fact, we have had ſome burning mirrours made of wood, of flax, and even of paper; itſelf a ſubſtance ſo eaſily capable of being conſumed. We are told of a perſon at Vienna, who made one of theſe that melted iron. It would be ſtrange enough to an uninitiated reader, when thus told that paper ſhould be made to receive an heat ſufficient to melt iron, and yet remain perfectly untouched by the fire itſelf. This man's name, if I remember right, was Neuman.

BUT the concave figure is not the only one by which the rays of the ſun are thus collected together; for any tranſparent convex body that permits the rays to paſs through it, will unite them in a focal point ſomewhere behind it. One of the glaſſes of a common pair of ſpectacles, if it be ſufficiently convex (that is gradually riſing in the middle) will burn wood, or any other ſubſtance that lies at the proper diſtance under its eye. We ſhall ſhew the manner how a convex glaſs thus directs the rays that paſs through it in a point behind, in another place (ſee fig. 56). Let it ſuffice to obſerve here, that if ſo ſmall a glaſs as that juſt mentioned has power to burn, what will not the power be of that made by Tſchirnhauſen, which was near four feet broad, an inch and an half thick, and whoſe focal point, or that point where all the rays were moſt collected, was twelve feet from the glaſs, ſo that it burnt with its greateſt force at that great diſtance. Stones, metals, earths, fled inſtantly away before it; it was obſervable alſo, that its ardour was moſt efficacious, when the ſubſtance to be conſumed was laid upon a piece of charcoal. Yet we muſt not ſuppoſe the effects of ſuch a glaſs equal to thoſe of the concave mirrour mentioned before. From its figure it cannot unite the rays into ſo ſmall a point as the former, and therefore muſt operate with leſs influence. Burning inſtruments of this kind are uſually made with glaſs; but any tranſparent ſubſtance that lets the rays paſs freely through, will anſwer the end as well. An hollow glaſs of the proper ſhape filled with water, has all the ſame effect as ſolid glaſs would have. And this was known to the ancients, for Lactantius aſſures us, that a globe filled with water, would kindle a fire even in the midſt of winter, which he thought ſtill the more ſurpriſing. A burning inſtrument may be thus made of horn, if very tranſparent, of Iſinglaſs, of glue, of ice itſelf. In fact, ice makes an excellent burning inſtrument. Take a piece of ice, put it into a common braſs ladle, and by melting, it will ſhape itſelf, in the bottom of the ladle, to the figure you propoſe, that is convex on one ſide and plain on the other. Uſe this as a burning glaſs, and it will anſwer rather better; particularly if the water has been boiled before it froze, ſo as to purge it of all its air.

THE effects of burning inſtruments, whether concave or convex, are great, always in winter, which is very extraordinary, ſince the heat which they collect is ſo much leſs at that ſeaſon. However, there may be a very good reaſon aſſigned for this ſeeming paradox. Vapours are found greatly to diminiſh the efficacy of the rays collected by the ardent inſtrument; charcoal burning and ſending up its vapour under the converging rays, enfeebles them ſurpriſingly. There are always leſs vapours in winter than in ſummer.

A burning mirrour not only collects the rays of heat, but of light alſo; ſometimes giving luminary rays ſuch a brilliancy as to dazzle, and, at laſt, deſtroy the ſtrongeſt ſight. Thus the light of the moon may be collected in the eye of a burning mirrour, with a ſplendour only inferiour to the united beams of the ſun; but notwithſtanding theſe beams are ſo very bright, they have no heat at all. Nor is want of heat in the moon beams to be wondered at; for by calculation it has been found, that the heat of this luminary is three million of times leſs than that of the ſun; but our beſt inſtruments can make the beams either of the ſun or moon, only three hundred times more powerful than they were before. So that the moon beams, even after they have been united together, are ſtill a thouſand times colder than the common heat of the ſun in the ordinary ſtate of nature.

Dufay, a French philoſopher, firſt tried the force of theſe inſtruments, in collecting the rays of a common culinary fire. Neither the concave mirrour, nor the convex glaſs, would collect the rays of a charcoal fire, when ſingle and alone; but by uniting their forces, he found that they had a moderate ſhare of force. He firſt took a large glaſs convex upon both ſides, ſo that the rays of the fire paſſing through it went out behind parallel to each other. Theſe rays thus tranſmitted were received upon the ſurface of a concave mirrour behind, which reflected them into a focus; however, they could burn only when the two inſtruments were but four feet aſunder. So very much are the rays of a culinary fire enfeebled by paſſing through the pores of glaſs, while the ſolar rays, on the contrary, ſeem to loſe very little of their force. The heat of a common fire is thus compoſed of groſs and maſſy parts, while that of the ſun is penetrating, light, and active. Is it to be wondered therefore, that the juices which are nouriſhed in the vegetable world by the ſolar heat, are light, pungent, and racy, while thoſe which culinary heat produces in an hot-houſe, are more vapid and leſs highly flavoured?

If a concave burning mirrour be placed before a large fire, it gives back the heat in a conſiderable degree, ſo as to be ſenſibly felt at thirty or forty paces diſtance. But it will not, however, be reflected into a focal point. An inſtrument of this kind might be uſeful in kitchens, to reflect, and thus double the heat of their fires. A learned Dutch writer adviſes cook maids, in general, inſtead of the ſpherically formed mirrours, to make uſe of the true parabolic curve; for then it will reflect the rays moſt exactly parallel to its axis.

CHAP. II.

Of Cold.

COLD is a quality whoſe nature, like that of fire, is beſt known by its effects. Whatever are the properties of fire, thoſe of cold ſeem to be directly oppoſite. Fire increaſes the bulk of all bodies, cold contracts them; fire tends to diſſipate their ſubſtance, cold condenſes them, and ſtrengthens their mutual coheſion. But though cold thus ſeems, by ſome of its effects, to be nothing more than the abſence and privation of heat, as darkneſs is only the privation of light; yet cold is ſeemingly poſſeſſed of another property, that has induced many to think it a diſtinct ſubſtance from heat, and of a peculiar nature. It is univerſally known, that when cold, by being continued, contracts and condenſes ſubſtances to a certain degree; if then its power be increaſed, inſtead of continuing to contract and leſſen their bulk, it enlarges and expands them; ſo that extreme cold, like heat, ſwells the ſubſtance into which it enters. Thus, in fluids, they contract ſenſibly with cold till the moment they begin to freeze; from thenceforward they dilate, and take up more ſpace than they poſſeſſed while in a ſtate of fluidity. When liquor turns to ice in a cloſe caſk, it is often known to burſt the veſſel. When ice is broken upon a pond it ſwims upon upon the ſurface; a certain proof of its being of a larger bulk than ſo much water.

WATER, after loſing its fire, by means of which it remains in a fluid ſtate, becomes more denſe; conſequently its particles mutually touch in a greater number of points, and therefore cohere more ſtrongly, to a degree, that water turns to a hard body, commonly called ice.

IF a very cold air is in contact with the ſurface of the water, there it firſt loſes its fire: and thus the cauſe of its fluidity being removed, the upper ſurface of the water turns to a film or ſkin of ice, formed by oblong threads or filaments. And this is the reaſon why water uſually begins to freeze on the ſurface.

As water in freezing becomes more denſe after loſing its fire, its intermediate ſpaces or pores become ſmaller, and being filled with air, this air comes to be compreſſed, and thus its elaſticity being heightened, it forces out of the pores of the water, aſcending in it, as being lighter than water, in the form of ſmall bubbles; and having reached the upper film of ice, their eſcape is there prevented, and thus they run into larger bubbles, when come into mutual contact. And this accounts for the great number of air-bubbles obſervable in ice. If by boiling, or by the air-pump, we diſcharge the air out of water, and then ſet it to freeze, the bubbles, it is true, will be fewer, but that it ſhall have none is not poſſible, becauſe the air can never be all of it diſcharged.

AND thus the air forming bubbles in ice, muſt expand it, and cauſe it to occupy a larger ſpace than water, and conſequently render it lighter, and make it float on the water. It ſhould therefore ſeem, that the ice of the water purged of air, ſhould be of equal weight with it. But experience ſhews the contrary. For ſuch ice laid on water floats in like manner, though ſinking much deeper in it than other ice. And it is not poſſible it ſhould be otherwiſe, as neither by boiling, nor by the air-pump, all the air can be diſcharged.

THE Florentine academicians attempting to diſcover the extent of the expanſion of water when turned to ice, found that the ſpace occupied by the water, was to that occupied by the ice to which it was froze, as 8 to 9. Again, they took a certain weight of water which they ſet to freeze, and filling the ſpace occupied by the ice, with water, and weighing it, they found the weight of the firſt to that of the ſecond water, as 25 to 28 $\frac{1}{19}$. Now 8 is to 9, as 25 is to 28 $\frac{1}{8}$. So that the ratio of 8 to 9 differs but little from that of 25 to 28 $\frac{1}{19}$.

FROM this extraordinary expanſion of water, we may readily conceive why it cracks the glaſſes in which it freezes. Huygens filled a ſtout gun-barrel with water, ſecuring it at both ends, and in twelve hours after it burſt with a loud exploſion. The Florentines filled a copper ball with water, and filing it down gradually, it at laſt burſt, by the water froze in it. Muſchenbroek, by calculation, found, that a force of 27,720 pounds was requiſite to tear this ball aſunder. At Peterſburg, in the winter of 1749, 1749, an iron bomb was burſt by water turned to ice. And we have inſtances of the havock produced in the ſubſtance of vegetables, trees, and even of ſplitting rocks, when the froſt is carried to exceſs.

Freezing is carried on much more expeditiouſly when the water is at reſt than when it is in motion; it is eaſy to aſſign the cauſe of this, as the ice is carried from one ſurface to another by filaments, the current is ſtill deſtroying them as ſoon as formed; and it would be as difficult for a ſpider's web to be formed while the wind was breaking and blowing the threads that formed it, as it is for the froſt to ſend forth its filaments in the proper order, for the general congelation of a river. In very great froſts however, rivers themſelves are frozen. I have ſeen the Rhine frozen at one of its moſt precipitate cataracts, and the ice ſtanding in glaſſy columns like a foreſt of large trees, the branches of which have been newly lopt away.

BUT though the current of the ſtream oppoſes its freezing, yet a gentle and hot wind frequently helps it forward. Fahrenheit aſſures us, that a pond which ſtands quite calm, often acquires a degree of cold much beyond what is ſufficient for freezing, yet no congelation enſues. If a ſlight breath of air happens in ſuch caſe to bruſh over the water's ſurface, it ſtiffens the whole in an inſtant. The water before congelation and in its liquid ſtate, ſinks the thermometer very low, which ſhews its exceſſive degree of coldneſs. The moment that by the air, or any other agitation, it begins to congeal, the thermometer riſes to the ordinary freezing point. The cauſes of all theſe are inſcrutable in the preſent ſtate of philoſophical experiments.

IN general, the ice of northern regions is much harder than that of the more ſouthern climates; and though it contains more air, yet its contexture is much ſtronger by reaſon of the greater degree of cold by which it is congealed. The ice of Spitzbergen and the Greenland ſeas is ſo hard, that it is very difficult to break it with a hammer. In our own climate we may, in general, form a very juſt conjecture, concerning the duration of froſt by the hardneſs of the ice. If in the beginning of the froſt, the ice is harder and more reſiſting than uſual, it is a ſign that the froſt will continue long in proportion. A machine might with a little ingenuity be made, that would diſcover this hardneſs with ſufficient preciſion. During the hard froſt of 1740, a palace of ice was built at Peterſburg after the moſt elegant model, and the juſteſt proportions of Auguſtan architecture. It was fifty-two feet long, and twenty feet high: the materials were quarried from the ſurface of the river Neva, and the whole ſtood gliſtening againſt the ſun with a brilliancy almoſt equal to his own. To increaſe the wonder, ſix cannons of ice, two bombs, and mortars, all of the ſame materials, were planted before this extraordinary edifice. The cannon were three pounders, they were charged with gunpowder and fired off; the ball of one of them pierced an oak plank at ſixty paces diſtance and two inches thick, nor did the piece burſt with the exploſion *.

IN melting of ice, if it be laid upon ſome ſubſtances it melts faſter than upon others, nor can we aſſign any cauſe for the difference; it melts ſooner in a ſilver plate than upon the palm of the hand, and it melts ſooner upon copper than on any other metal whatſoever. Ice melts ſooner in water, than expoſed to the air of a ſimilar temperature. Sooner in water a little warm than near the fire when it is hotter. It melts ſooner in the void, than expoſed to the atmoſphere. If it takes twenty minutes

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* M. de Mairan Diſſert ſur la Glace. Part. II. Sec. 3. Chap. 3.

to diſſolve in open air, it will be but four minutes diſſolving in the exhauſted receiver.

THOUGH ice be a hard body, yet it is ſubject to a conſtant evaporation when the cold in the air is exceſſive. Perrault found, that four pounds of ice, which lay expoſed for 19 days in the open air, was lighter by a whole pound. M. Mairan, in the year 1716, in which, for ſome days, the cold was as ſevere as that of the winter 1709, alſo found that ice, which had lain in the air and in a northerly wind, had loſt in 24 hours above a fifth in weight: from which we may, at the ſame time, perceive the reaſon, why ſnow, lying expoſed in a continued cold on the earth, becomes diminiſhed in quantity.

WE have hitherto conſidered cold and freezing, as effects ariſing barely from the abſence of heat. There is, perhaps, ſomething actual or real in this caſe; poſſibly a body, which expels the particles of fire out of other bodies, while itſelf forces into their pores, and thus coagulates the fluid matters; that is, conſtrains or binds their parts, in ſuch a manner as to cohere ſtrongly together. The diffidence which one ſhould entertain concerning his concluſions, gives weight to this thought, and the experiments performed with ſalts will enhance it.

IF a thermometer is ſet in cold water, and you remark how far the ſpirit ſinks; then throwing in ſaltpetre, you will obſerve the ſpirit to ſink deeper ſtill, after the ſaltpetre is diſſolved in the water. The ſame thing happens, if inſtead of ſaltpetre, you uſe common ſalt, or which is better, ſal ammoniac.

WATER congeals in a glaſs which is ſet in ſalted ſnow: and, if only the under part of the glaſs ſtands in the ſnow, the congelation happens from below

low upwards, and then we may plainly perceive the manner in which the air is diſcharged out of the water. In this caſe, the glaſs does not readily ſpring or fly; but if you cover it entirely with ſalted ſnow, in order to promote a congelation all over, and thus prevent the diſcharge of the air, the glaſs flies.

As heat expands ſolid bodies, ſo cold contracts them. On the expulſion of the heat, the parts of the body draw cloſer together, and thus their matter is reduced to a ſmaller compaſs. Now, as a body becomes cold on loſing its heat, it becomes denſer in the proportion of the cold; and yet not in an infinite progreſſion, nature ſetting bounds to both.

COLD and heat affect the pendulum rod of clocks, the firſt contracting or ſhortening, and the laſt dilating or lengthening it, and thus altering its motion; which is attempted to be remedied, by oppoſing expanſion to expanſion, and contraction to contraction.

IRON is hardened by cold, upon making it firſt glowing hot, and then quenching it in cold water or moiſt loam; theſe are bodies which quickly deprive iron of its heat; and being thus cooled at once, it becomes denſer, its parts coming cloſer together; and thus touching in a greater number of points, they cohere the more ſtrongly, and conſequently the iron is made harder.

THE Thermometer is the common meaſure for the degrees of heat and cold; but whether a juſt one may be doubted. And firſt, the glaſs of the thermometer expands with heat, and thus hinders the aſcent of the ſpirit, and contracts with cold, thus preventing its fall. Then, in a great degree of cold, the air is diſcharged out of the ſpirit, and fills that part of the glaſs which ſhould have no air, and by its elaſticity oppoſes the riſing of the ſpirit. And laſtly, it is ſuppoſed, though groundleſsly, that the heat is proportional to the expanſion of the ſpirit, though the contrary appears by the pyrometer.

If you pour water on a table, and place on it a tin plate with ſalted ſnow, the plate will be frozen to the table, as ſoon as this ſnow begins to melt. For as the water is much warmer than the ſalted ſnow, the fire muſt force out of the water into the plate, and from this laſt into the ſalted ſnow. And thus the water loſing its heat, turns to ice; and on the contrary, the ſnow being heated, muſt melt, before which the plate is not froze to the table, the particles of fire being then gone over into the ſnow out of the water. This experiment may be made, though you ſet the plate with the ſalted ſnow over glowing coals, kept conſtantly blowing. On the plate with the ſnow lay another plate with cold water, and ſtirring with a cane, or any other inſtrument, the ſnow will diſſolve, and ice will be formed upon the water in the diſh. I have tried it frequently without ſalt, and it anſwers, though not with equal efficacy.

BUT by this method we can only then make ice when we are poſſeſſed of ſnow or ice already: Boerhaave gives us a method of making ice without them. We muſt have for this purpoſe, at any ſeaſon of the year, the coldeſt water we can get; this is to be mixed with a proper quantity of ſalt, at the rate of about three ounces to a quart of water; another quart of water muſt be prepared in the ſame manner with the firſt; the ſalt, by being diſſolved in each, will make the water, as was ſaid above, much colder than it was before; they are then to be mixed together, and this will make them colder ſtill. Two quarts of water more prepared and mixed in the manner of the two firſt, are to be mixed with theſe, which will increaſe the cold in a much higher degree in all. The whole of this operation is to be carried on in a cold cellar; and a glaſs of common water is then to be placed in the veſſel of liquor thus artificially cold, which will be turned into ice in the ſpace of twelve hours. Of all ſalts, *ſal ammoniac* beſt anſwers this intention.

BUT of late there has been a more effectual method of congealing fluids than any yet mentioned. It has been diſcovered, that fluids ſtanding in a current of air, grow by this means much colder than before: it has been diſcovered alſo, that all ſubſtances grow colder by the fluids they contain, or are mixed with, being evaporated. If both theſe methods therefore are practiſed upon the ſame body at the ſame time, they will increaſe the cold to almoſt any degree of intenſeneſs we deſire.

THE Ruſſian experiment at Peterſburgh of congealing quickſilver was thus: at a time when the quickſilver was found to have fallen extremely low, and the cold conſequently to be very intenſe; the mercury being by De Liſle's thermometer, which is beſt adapted for meaſuring the degrees of cold, as Fahrenheit's for meaſuring thoſe of heat; being I ſay, by this thermometer, fallen to 250 degrees, they increaſe the cold by mixing the fuming ſpirit when it becomes red, and being left to cool in ſnow, with half as much ſnow in a common glaſs, ſtirring it till it becomes of the conſiſtence of pap in the uſual manner, by a mixture of ſpirit of nitre with ſnow; the thermometer being dipped into this compoſition, the quickſilver ſunk to 470 degrees. Upon a repetition of this experiment, when the mercury (which, contrary to the manner of water, inſtead of dilating, ſtill continued to contract with increaſed cold) ſunk to 500 degrees, they broke the glaſs, and it was found frozen into a hard ſolid maſs; but what is moſt extraordinary, it bore the hammer like a common metal, and was beat into the ſhape of an half-crown. At laſt, however, it began to break, and being thawed, recovered its former fluidity. From hence we ſee, that the ſpirit either of ſalt or nitre are poſſeſſed of the power of cooling liquors in a much higher degree than the common ſubſtances in concrete. Common nitre, or ſaltpetre, for they are the ſame, ſinks the thermometer to eleven degrees. Spirit of nitre will be found to ſink it eight degrees ſtill lower, as has been diſcovered by Fahrenheit.

CHAP. III.

OF LIGHT.

AS by the degrees of cold or heat in bodies, we are led to eſtimate the quantity of fire they contain; ſo alſo we have another method of aſſuring ourſelves of the exiſtence of fire in different ſubſtances, by the light they ſend forth; for wherever there is light, there is fire. Heat and light may be conſidered as the children of fire; as kindred qualities produced by the ſame cauſe, but ſometimes exerting their powers ſeparately, and ſometimes united. It is the ſame fire, whoſe heat burns in the melting metal unſeen, and whoſe light ſhines harmleſs in the glow-worm. This light, though ſeemingly inoffenſive, would burn if collected into a ſmall compaſs, like the fierceſt flame; but no inſtruments that art has yet found out, are able to give its parts a ſufficient conſiſtence.

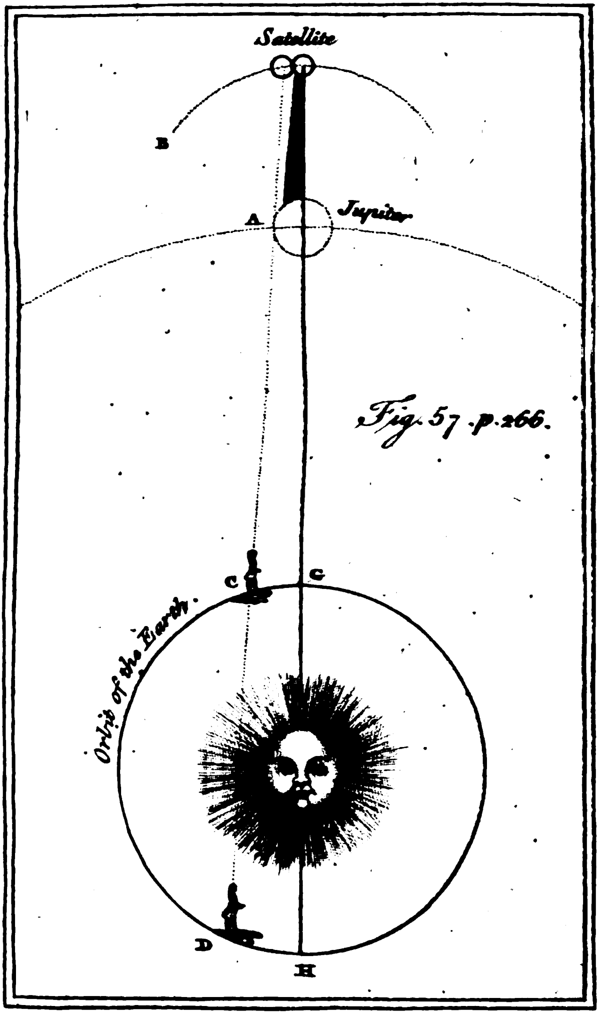
The flame which hangs over burning ſpirit of wine, we all know to ſcorch with great power; yet theſe flames may be made to ſhine as bright as ever, and yet be perfectly harmleſs. This is done by placing them over a gentle fire, and leaving them thus to evaporate in a cloſe room without a chimney: if a perſon ſhould ſoon after enter with a candle, he will find the whole room filled with innoxious flames. The parts have been too minutely ſeparated, and the fluid perhaps has not force enough to ſend forth its burning rays with ſufficient effect. However this be, we may ſafely conclude, that the parts of fire may be ſo ſeparated, as to become harmleſs, and yet they may retain all their former ſplendour.

SINCE we thus ſee light and heat are the moſt obvious indications of fire, we have no reaſon to doubt, but that the ſun, who is the great fountain of both, is itſelf one large body of that element.

In what manner that great fiery maſs is fed, with continuing fuel to keep up his force, is a queſtion equally uſeleſs and impoſſible to be reſolved; whether comets travel from other ſyſtems with a proviſion of this nature, or whether the etherial vapours come from all parts with their ſupply, is not worth enquiring after. He that made the comet ſweep through immeaſurable tracts of ſpace, could with equal eaſe give permanent fire to the ſun: we feel the conſtancy of his flame, and can ſee ſcarce any diminution of his ſplendour. It is enough for philoſophy to inveſtigate the nature of this heat and light; the things with which man has the neareſt concern, ſhould be the chief objects of his curioſity.

SETTING aſide other ſyſtems therefore, we know that the rays of the ſun's light and heat are darted foreward from his body in ſtraight lines. If we make a ſmall hole in a dark room, and permit a ray of the ſun's light to enter, we ſhall ſee it dart againſt the oppoſite part of the wall or floor, in the ſtraighteſt line. Did the beams of the ſun diffuſe themſelves in any other manner, for inſtance as water or air are known to do, the ray, upon once entering the room, would ſoon fill the whole chamber with light: but this we know to be contrary to every hour's experience. The rays of light therefore dart directly forward from the ſun, and reach our earth with the ſwifteſt progreſſion. It might by the uninitiated be thought a taſk beyond the reach of human abilities to calculate exactly, how long a ray of light is upon its journey, in travelling from the ſun to enlighten our hemiſphere. Yet this has been attempted by Romer, who finds that light travels at the rate of an hundred and fifty thouſand miles in a ſingle ſecond; and that it is ſeven minutes in paſſing from the ſun to the earth, which is nearly a diſtance of ſeventy millions of miles. The ſtudent may deſire to know how he made this calculation, it was thus:

WHEN the earth in going its annual revolution round the ſun is at C, (ſee fig. 57.) an eclipſe is obſerved of a ſatellite of Jupiter, which thus regularly ſuffers eclipſes every forty-two hours and an half. If the earth never left C, but continued there immoveable, it would regularly ſee the ſatellite eclipſed at the expected interval of forty-two hours and an half: and alſo at thirty times that number, the ſpectator would ſee thirty eclipſes. But the earth is not fixed; it travels onward to D, and a ſpectator does not ſee thirty eclipſes in the ſtated period, and not till ſome minutes after; for the further off the earth removes, the light takes ſo much time to travel acroſs the annual orbit from C to D. From C to D it takes up about ſixteen minutes in travelling. Now the ſun is nearly half-way between C and D, and therefore the light travelling from him, muſt



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muſt perform its journey in half ſixteen, that is, in eight minutes, or thereabouts.

SUCH is the rapidity with which theſe rays dart themſelves forward, that a journey, they perform thus in leſs than eight minutes, a ball from the mouth of a cannon would not complete in ſeveral weeks. But here it may be ſaid, if the velocity of the light is ſo very great, how is it that it doth not ſtrike againſt objects with a force equal to its ſwiftneſs? If the fineſt ſand, the objector may continue to obſerve, were thrown againſt our bodies with the hundredth part of this velocity, each grain would be as fatal as the ſtab of a ſtiletto: how then is it, that we expoſe without pain, not only other parts of our bodies to the incurſions of light, but our eyes, which are a part ſo exquiſitely ſenſible of every impreſſion? To anſwer this objection, experiment will inform us, that the minuteneſs of the parts of light are ſtill ſeveral degrees beyond their velocity; and they are therefore harmleſs, becauſe ſo very ſmall. A ray of light is nothing more than a conſtant ſtream of minute parts ſtill flowing from the luminary, ſo inconceivably little, that a candle, in a ſingle ſecond of time, has been ſaid to diffuſe ſeveral hundreds of millions more particles of light, than there could be grains in the whole earth, if it were entirely one heap of ſand. The ſun furniſhes them, and the ſtars alſo, without appearing in the leaſt to conſume, by granting us the ſupply. Muſk, while it diffuſes its odour, waſtes as it perfumes us; but the ſun's light is diffuſed in a wide ſphere, and ſeems inexhauſtible.

HIS rays travel onward without hinderance or mutual interruption; winds meet and deſtroy each other's force, but the rays of light never oppoſe their mutual progreſs. If we place a row of candles (ſays the ſenſible Mr. Ferguſon)

Ferguſon) on a table, and let them dart rays through a pinhole in a piece of black paper, theſe rays being received upon any object not too far off, will be formed into as many ſpecks of light, as there are candles; each ſpeck being diſtinct and clear, the rays from one candle being no way deſtroyed, by any interruption of thoſe from another. The rays of a torch may be overpowered, and ſeem loſt in the brighter rays of the ſun, yet ſtill the ſmaller candle actually ſhines with undiminiſhed radiance; as we may ſee by looking at it by night and by day through a teleſcope.

As light is thus driven forward in rays from a center, it muſt decreaſe, as all rays do, in proportion as the diſtance ſquared becomes greater. Gravity, ſounds, and light are, in this reſpect, ſimilar; a luminary that enlightens the mountain's ſide at a mile diſtance, will illuminate four times as feebly at two miles diſtance. If I can but juſt read with a candle placed a yard from me, I muſt have four candles if they are placed two yards off. In a word, the quantity of light decreaſes inverſely as the ſquare of the diſtance.

To make any body viſible, it is neceſſary that the rays of light ſhould fall upon it; otherwiſe it will paint no image on the eye, nor tranſmit any but that of darkneſs to the mind. Objects placed in a dark room cannot be ſeen; but if the ſaſh be lifted up, and the light be thrown in a greater quantity, we may have a confuſed idea of the figure of the furniture; however, until the room be entirely illuminated, and the rays that fall on every object be reflected back to our eyes, we can have no diſtinct perceptions. For this reaſon, a perſon who remains himſelf in the dark with an hole to peep through, can ſee all objects without, becauſe their rays can be reflected to his eye; but, as was ſaid before, he cannot from without ſee clearly into a dark room, becauſe there are too ſmall a number of rays ſent from thence to form the picture of the object in his eye.

When I uſe the word Picture, it ſhould be underſtood in the moſt literal ſenſe. Every object that we behold has its picture drawn moſt exactly, and in colours far beyond the reach of art, on the back part of the eye. To be convinced of this, we have only to take the eye of an ox or ſheep, and ſtripping off all the coats to the laſt internal one behind, place it ſo in the hole in the window ſhutter of a dark room, ſo as that no light whatſoever ſhall enter but through the eye itſelf thus prepared. Then taking a ſheet of white paper, and holding it nearer or farther off behind the eye, the ſpectators will perceive a moſt beautiful picture of the objects without thrown upon the paper, through the humours of the eye. Every object, however, will be inverted upſide down upon the paper, or, as the vulgar expreſs it, they will all ſtand upon their heads, the cauſe of which demands explanation.

BUT before we enter into a more minute illuſtration of the manner in which viſion is performed, we muſt explain more minutely the nature of light itſelf, by which the eye is thus made capable of ſeeing.

CHAP IV.

Of the Refraction of Light.

WE have ſeen that the parts of light are extremely ſmall, and flow from the ſun with inconceivable rapidity. We obſerved alſo, that they darted from that great luminary in ſtraight rays ; but this is not entirely the caſe, for the rays may be bent into crooked lines by paſſing through tranſparent bodies of different denſities. We ſee a ſtick when put into water, appear as if it were broken, at the ſurface of the water, in two. We ſee through ſome glaſſes bodies appear enormouſly large, and through others they appear extremely little. Through ſome they ſeem near, and through others remote. From whence ariſe theſe ſtrange appearances, or what is the cauſe which thus bends the ſtraight ſtick ſeemingly into a curve; apparently that magnifies the bulk of one object, or diminiſhes that of another? All theſe wonders ariſe from the ſame cauſe; the rays of light, in paſſing through different tranſparent ſubſtances, take different directions. To explain this:

PHILOSOPHERS have agreed to call any tranſparent body, through which light paſſes a *medium*. Air is a medium; water, glaſs, diamonds are mediums; wherever light paſſes, though it be a vacuum itſelf, they call that a *medium*. Now, while the rays of light dart through any medium of uniform denſity, they are ſtraight; but when they paſs obliquely through one medium into another, then they are *refracted*, broken, or driven out of their right lined courſe into a crooked direction. As a ſtraight ſtick one half in the medium of water, and the other half in the medium of air, appears broken in two, juſt where the two mediums unite.

To ſhew that a ray of light is thus refracted by paſſing from air to water, an

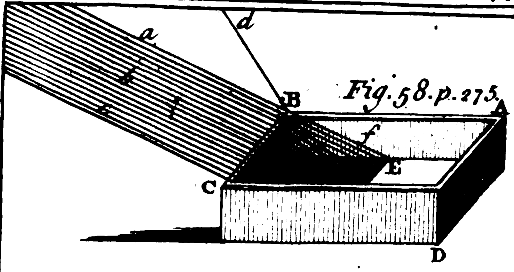


Fig.58.p.275.

Fig.59 & 60.p.277 & 281.

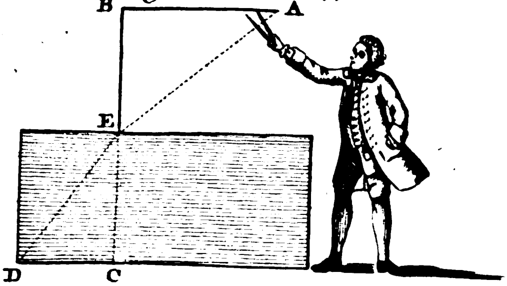
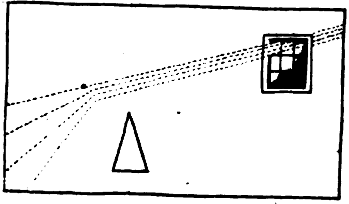


Fig.61.p.281.



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an eaſy experiment will ſuffice. Let a ſun beam be permitted to enter into the room by an hole; but it is not neceſſary that the chamber ſhould be darkened for this purpoſe. Then ſet an empty veſſel, as A B (ſee fig. 58) in ſuch a poſition, that the ray ſhall firſt glance upon the edge of the veſſel, and then fall upon the bottom. Put a ſhilling at the bottom E. where the ray falls; then fill the veſſel with water. We ſhall find that then the ray will not fall upon the ſhilling at E, but fall nearer under the edge B C. So that the ray will now fall more perpendicularly to the ſurface of the water, than it would if it had ſuffered no refraction.

As the ray is thus refracted or broken more into the perpendicular, in paſſing from the air into the water, ſo will it be refracted, in a contrary way, in paſſing from water into air. For, let us ſuppoſe, the veſſel once more empty, and the ſhilling at E hiding its rays from the ſpectator's eye, at F. If the veſſel be then filled with water, the rays of light, now paſſing from the denſer medium of water into the thinner medium of air, will firſt mount up almoſt perpendicularly to C. and then getting into the air will paſs more obliquely forward to hit the ſpectator's eye. So that the ſhilling will thus become viſible. Juſt thus the ferrel of my cane, if put into the water, would appear raiſed, like the ſhilling; and therefore, if the ferrel be raiſed, the other parts of the cane that are in the water, muſt alſo be raiſed nearer to the eye, ſo that it will appear broken in two, juſt where the air and water meet. Thus then, we have ſeen that a ray of light, paſſing from a thinner medium into a denſer, as from air into water, is refracted more directly downward, or more perpendicularly to the ſurface of the denſe medium. On the contrary, the ray, paſſing from water into air is, upon its entrance into the air, ſent forward more obliquely. Hence then, we may univerſally conclude, that the denſer the medium, the more perpendicularly to its ſurface are the rays of light refracted. To give the learner the moſt diſtinct ideas poſſible of this, we ſaid, the refraction of light was greateſt in the denſeſt mediums. Suppoſe the ray A E (ſee fig. 59) falls upon a vaſe of water, it is refracted from the ſtraight line at the ſurface of the water to D. Let us ſuppoſe the perpendicular B E C drawn to the ſurface of the water, the ray of light A E makes an angle with the perpendicular B. It alſo makes a different angle with the ſame perpendicular, in going from E to D. The difference between theſe two angles is that which meaſures the greatneſs of the refraction of the ray. The two angles always bear a conſtant proportion to each other. The greater the angle A B, the greater will be the angle D C. To know the names uſed in ſcience is, at laſt, become a part of ſcience. The angle B A thus made by the perpendicular and the ray, before refraction, is called the angle of incidence. The angle D C, made by the ſame lines, after refraction, is called the angle of refraction.

NOW then, a ray of light paſſing from air to water, is found by experience to have its angle of incidence B A, bearing the ſame proportion to its angle of refraction D C as three does to four; or in other words, it is a fourth part greater in the air than in the water. In glaſs, the angle of incidence is a third part greater than the angle of refraction, the proportion being about three to two. Diamond refracts moſt of all, the angle of incidence being three times greater than the angle of refraction.

FROM hence then we may be aſſured, that the denſer the medium, the more perpendicular does a ray of light, falling on its ſurface obliquely, paſs through it; that is, it takes the ſhorteſt way. It takes a ſhorter cut in paſſing through diamond than glaſs, and through glaſs than through water; ſo that we ſee, the denſer the body the more readily it pervades them. This is very extraordinary, and very different from the nature of other bodies, paſſing through obſtructing mediums. If I ſhould throw a leaden bullet obliquely into the water, it would not reach the bottom in the direction I had given it, but the water would in ſome meaſure keep it buoyant, and it would come with a greater ſlant to the bottom. But it is very different with a ray of light; when it darts obliquely on the ſurface of the water, it then begins to deſcend more perpendicularly downwards. What can be the cauſe of this extraordinary diverſity in the operations of nature? Several philoſophers have attempted this ſolution in vain: Newton attempted, and it no longer appeared a ſecret. The cauſe of light being thus perpendicularly refracted by the moſt denſe mediums, is, that the parts of it are moſt attracted by the moſt denſe mediums. All bodies as we well know, attract and are attracted in proportion to their quantity of matter. The light, from its minuteneſs, paſſes with equal eaſe through the hardeſt diamonds or the ſofteſt air; it meets in the denſeſt mediums nothing to retard its progreſs, but much to increaſe its celerity, for it obeys the influence of their ſuperior attractions. Every inſtant of its deſcent or progreſs through the denſer mediums, it feels new influence from the attracting power. A bullet thrown from the hand obliquely into water, goes downward yet more obliquely; for the water in ſome meaſure, takes off from its natural gravity and keeps it buoynant: a ray of light, on the contrary, darting obliquely upon the water, has the obliquity of its fall interrupted by attraction, and conſequently falls more perpendicularly down; though, rigorouſly ſpeaking, the ray, in its deſcent through water or glaſs, is not refracted from the ſurface to the bottom in a ſtraight line, but a crooked one; ſo that the line from E to D (ſee fig. 60.) is an abſolute curve.

THAT bodies have this power of attracting the rays of light, may be known from the following eaſy experiment. Set a ſmall pointed penknife ſtanding with its point upward; (ſee fig. 61.) let the room be made perfectly dark, and a ray of light be permitted to glance in, ſo as juſt to touch the point of the penknife: the ray, upon touching the metal will bend itſelf in ſuch a manner, that the part of it which is neareſt the point, will be moſt refracted, and that fartheſt from the point, will ſuffer the leaſt refraction; a proof, that the metal attracts thoſe neareſt it with the greateſt force. If the point thus can refract the rays by its attracting power at a ſmall diſtance, any denſe ſubſtance through which they paſs muſt more powerfully attract them, as the diſtance is nothing.

CHAP. V.

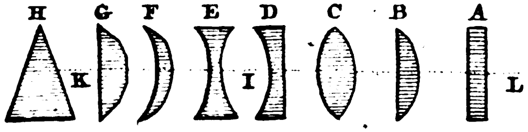
Of the Paſſage of Light through Glaſs.

WE have ſeen the manner in which water refracts the rays of light that paſs through it; but the conſideration of that part of the ſubject, though pleaſing, is only a matter of curioſity; an inveſtigation of the manner of its refractions through glaſs is connected very nearly both with our neceſſities and pleaſures. When a ray of light paſſes out of air into glaſs, its angle of incidence is to its angle of refraction, as we ſaid above, as three to two; that is, the angle of incidence is a third part larger than that of refraction: upon this ſingle principle depends the whole theory of viſion through glaſſes.

Glaſſes are uſually ground by the glaſs-grinders who deal in this ſubject, into eight different ſhapes. For firſt, the glaſs may be flat on both ſides, as the common pane of a window. Or 2dly, it may be flat on one ſide and convex on the other, B A (ſee fig. 62) Or, 3dly, it may be convex on both ſides, like our ordinary reading glaſſes, C. Or, 4thly, it may be flat on one ſide and concave on the other, as D. 5thly, It may be concave on both ſides, like the glaſs near-ſighted people generally uſe, as E. 6thly, It may be concave on one ſide and convex on the other, like the cryſtal of a watch, though not in ſuch a degree, as F; this is uſually called a meniſcus. 7thly, It may have one ſide, which muſt be convex, ground into little facets, like thoſe of ſome jewels, while the other ſide is plain. Children know it by the name of a multiplying glaſs, as G. 8thly, A priſm, which from its importance in explaining ſeveral properties of light to be mentioned in the ſequel, I ſhould have named firſt. The priſm is a longiſh piece of glaſs which has three flat ſides, beſides the two ends. I do not well know, even by a cut, how

to

Fig. 62. p. 284.



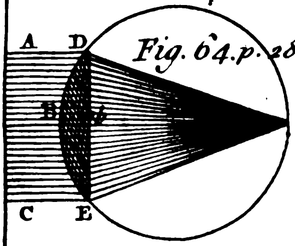


Fig. 64. p. 286

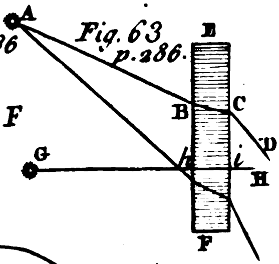


Fig. 63 p. 286.

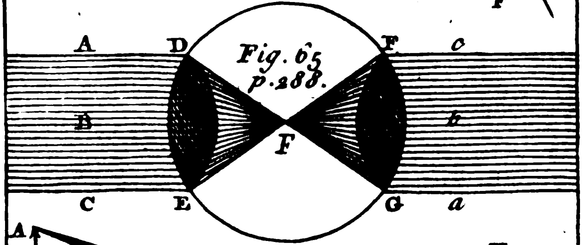


Fig. 65 p. 288.

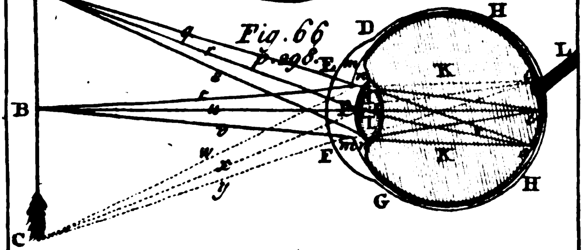


Fig. 66 p. 298.

Proud Sc

to give the learner an idea of its figure. A three ſquare razor ſtrap, as the vulgar expreſs it, will give a reſemblance of the priſm. I have ſeen the ſhank of a large drinking glaſs taken and ground down, ſo as to have three flat ſides, which anſwered all the purpoſes of a priſm tolerably well. All theſe glaſſes mentioned above, are called by the common name of Lenſes.

The more obliquely a ray of light falls upon any one of theſe, as we ſaid before, the greater will be the angle of incidence, and conſequently greater will be the angle of refraction. If, therefore, the ſolar rays fall upon one of theſe glaſſes with a ſurface not quite flat, but irregular, it is very evident that the ſame rays will fall with different obliquities upon theſe different ſurfaces, and conſequently be differently refracted, or bent, in their paſſage through the glaſſes. Let us illuſtrate this in every particular glaſs.

A ray of light A B C falling (ſee fig. 63) perpendicularly on a plain glaſs, is never refracted; but if it falls obliquely it will be refracted upon its entrance into the denſer glaſſy medium, and be again refracted upon its exit from behind the glaſs into the air, It will alter its direction as it goes into the glaſs; but upon going out, it will reſume the ſame direction with which it entered. Thus it will be refracted in the line B C, upon entering; and upon going out will be again refracted in the line C D.

If ſeveral rays of light fall together on a glaſs E D, convex on one ſide (ſee fig. 64) they will be differently refracted, in proportion to the obliquity with which each of them falls upon the ſurface. The middle ray, for inſtance, which paſſes perpendicularly through, will not be refracted at all, but go on ſtraight forward. All the other rays, however, will ſuffer refraction. The ray C E will be refracted upwards to F; the ray A D will be refracted downwards to the ſame point. There they will croſs, and then go onward, diverging or ſeparating from each other for ever; that which came from the bottom going upward, and that which came from the top downward. The figure we have given there is flat, but it muſt be ſuppoſed round, the glaſs being repreſented edgeways. If ſo, therefore, the collected bundle of rays, paſſing through the glaſs, unite and form a cone, or a figure like a candle extinguiſher, the bottom of which is at the glaſs, and the point at F. This point, as we once before had occaſion to mention, is called the focus of the glaſs. From a calculation in deep geometry we learn, that the diſtance from this point is always equal to the diameter of the circle which the glaſs would make if its convexity were continued.

WHEN the rays of the ſun fall directly upon a glaſs D E (ſee fig. 65) equally convex on both ſides, they will be refracted ſtill more abruptly, and meet ſooner in a point or principal focus at F. The diſtance of this focus is, we are informed by the ſame abſtruſe calculation, equal to the ſemi-diameter of the circle, which the convexity of the glaſs continued would make. Either this glaſs or the former, as they collect the rays of the ſun into a point, will burn at that point, ſince the whole force of the rays is concentrated there.. Their ſurpriſing power in this way we have had occaſion to mention before. The broader the glaſs in theſe inſtruments, the greater will be its power.

As parallel rays, ſtriking upon theſe glaſſes, are thus converged to a point, it muſt naturally follow, that when the rays, diffuſing themſelves from a point, as from a candle, ſtrike one of theſe glaſſes, they will be refracted parallel.

If, therefore, we place a candle at a focal diſtance from one or both of theſe glaſſes, as at *f*, its rays will, upon going through the glaſs, all run parallel to each other. If the candle be placed nearer the glaſs than its focal diſtance, the rays, after paſſing through the glaſs, will no longer run parallel, but ſeparate or diverge: if it be placed further off, the rays will then ſtrike the glaſs more parallel, and will therefore, upon paſſing through it, converge or unite at ſome diſtance behind the glaſs.

But it is very remarkable, that where theſe rays fall, as in the ſolar rays, they not only unite, but they alſo form an inverted picture of the flame of the candle, as may be ſeen on a paper placed at the meeting of the rays behind! How the image is inverted is eaſy to apprehend; for we obſerved above, that the upper rays, after refraction, were ſuch as came from the under part of the luminous body; and that the under rays, on the contrary, came from its top: ſo that the rays are turned up-ſide down, and ſo conſequently is the image. It is very pleaſing to view a picture of this kind thus formed, each ray preſerving the colour it had in the luminous object, with the moſt imitative preciſion. The ſhadings of the little piece are far beyond the reach of art, and the deſign far more correct than that of the fineſt painter. We mention the candle as being an obvious luminary; but if any object whatſoever be placed at the proper diſtance from a convex glaſs, its picture will be in the ſame manner thrown behind, and may be received upon paper, or any other body whatſoever, in all its natural proportions and colourings. The nearer the natural object is to the refracting glaſs, the farther off will this picture be behind it; becauſe, as we ſaid before, the rays which form it do not then converge or unite, but at a great focal diſtance. The farther off the natural object is, the nearer will be the focal diſtance it makes, and conſequently the nearer will be the picture behind the glaſs; for wherever the focus is, there will the perfect picture be. However, when the rays come from ſeveral objects at a moderate diſtance, they may be then conſidered as all parallel, and this difference of focus is then imperceptible.

To put what has been ſaid in other words — As the rays of the ſun may be all conſidered as falling parallel upon every glaſs of the convex kind, ſo they muſt always unite behind it in a focal point. As all the rays flowing from other objects are not always parallel, when placed too near the glaſs, they ſeparate after refraction, and run off divergent; when placed at a proper diſtance, they unite or converge in a focal point, and there imprint a picture, if there be any thing properly placed to receive it, in which the natural figure will be repreſented, its motions, its colours, and ſhadings.

THE whole foregoing theory may be demonſtrated with a common reading-glaſs. If a candle is held ſo near it, as that the rays paſſing through ſhall ſtrike the wainſcot of the chamber with a bright ſpot, juſt as large as the glaſs itſelf, the candle is then at the focal diſtance; and rays, ſtriking the glaſs divergently, are refracted through it, parallel to each other, neither ſpreading nor drawing together as they proceed. If the candle is held nearer than the focal diſtance, the rays will fall then more divergent upon the glaſs, and will conſequently be refracted more divergent, ſo that they will form a very broad ſpot of light upon the wainſcot. If the candle be placed at a much greater diſtance than the focus, the rays fall upon the glaſs more parallel, and conſequently when they are refracted will tend to unite and converge behind the glaſs, and will form but a ſmall ſpeck of vivid light on the wainſcot. This ſpeck, if cloſely examined, will appear a perfect picture of the candle.

Every viſible point, in any body whatſoever, may be conſidered as a candle ſending forth its ray, which ſplits and *pencils* out into ſeveral other rays before it arrives at the eye. Each body is as if compoſed of an infinite number of ſplendid points or candles, each point with its own radiance, and diffuſing itſelf on every ſide. Inſtead of one body, the eye in fact is impreſſed with thouſands of radiant points ſent out from that body, which being grouped at the bottom of the eye, imprint the picture of the object from whence they flow. Each point ſends forth its ray.

Now, if, inſtead of candle light, we uſe that of the ſun, by holding this glaſs oppoſite his beams, as theſe all ſtrike the glaſs parallel to each other, they will be united ſoon into a focus behind, and where they unite will burn with great fierceneſs. Suppoſe we adapt this glaſs, ſo as to fit an hole in the window-ſhutter of a darkened chamber, ſo as that no light ſhall come into the room but through the glaſs; then let us place a ſheet of white paper behind it at the proper diſtance, we ſhall thus have a *camera obſcura*; for a picture of every external object will paſs through the glaſs, and be painted upon the paper in the moſt beautiful colours that imagination can conceive, and all the motions of thoſe objects alſo. It is neceſſary, in this experiment, that the window ſhould not be oppoſite the ſun; for then we ſhould ſee no image but that of his brightneſs: and yet it is neceſſary alſo, that while we make the experiment, the ſun ſhould ſhine and illuminate the objects ſtrongly, which are to paint themſelves within. Without this ſtrong illumination, the rays will be ſent ſo feebly from every object, that we ſhall have but a very faint picture, if any at all.

PAINTERS and architects often make uſe of a ſimilar contrivance to take a draught of landſkips or buildings: their glaſs is fixed in a box, and by means of a mirrour, on which the objects fall, they are reflected upon oiled paper properly placed, upon which the artiſt ſketches his draught. With regard to the contours, or out-lines, which this picture gives, nothing can be more exact; but, with regard to the ſhading and colouring, the artiſt can expect but little aſſiſtance from it: for, as the ſun is every moment altering its ſituation, ſo is the landſkip every moment varying its ſhade; and ſo ſwift is this ſucceſſion of new ſhade, that while the painter is copying one part of a ſhade, the other part is loſt, and a new ſhade is thrown upon ſome other object.

If ſuch a glaſs be ſo fitted to an hole in a dark lantern, ſo that little pictures, painted in tranſparent colours on pieces of glaſs, may be paſſed ſucceſſively along between the glaſs and the candle in the lantern, we ſhall thus have a magic lantern. The pictures, ſtriking the glaſs very divergent, will be refracted very divergent alſo, and will be painted upon the wall of the chamber in all their colours, as large as we pleaſe to make them; for the farther the wall is from the glaſs, the more room will the rays have to diverge. To illuminate the little figures more ſtrongly, another glaſs muſt be uſed, which may either reflect or refract the light of the candle upon them.

But of all the optical inſtruments that we know, thoſe made by art are nothing to the natural one of the eye, which has its convex glaſſes, and differently refracting mediums, all adjuſted in the moſt admirable order, while a fine tapeſtry is hung behind to receive the image from without. But, to quit tawdry common-place obſervations, let us deſcribe the *eye* itſelf, and trace Nature through her various operations in that wonderful piece of mechaniſm.

CHAP.

CHAP. VI.

Of the Eye.

THE eye is nearly globular, as we may eaſily obſerve by the eyes of ſheep or oxen when taken out of the head. But it is not perfectly round; for, if I may uſe the expreſſion, it bliſters out a little before, as at E, (ſee fig. 66.)

WE all know that the eye of an ox is compoſed of an external coat or ſkin, which, like a bladder filled with water, contains a fluid within it. This external coat is made up of three coats, one without the other, like the bark of a tree, which may be ſeparated into three coverings; and the fluid within alſo is eaſily diſtinguiſhed into three tranſparent humours of different denſities,

ties; one of them as thin as water, the other like jelly, and the third as hard as gum arabic.

BUT firſt as to the three coats of the eye. When we take the eye of an ox from the head, we firſt find an outward fleſhy ſkin almoſt covering the ball of the eye, which does not properly belong to it, but to the ſkull. It is not reckoned among the coats of the eye, although it makes what we call the white of the eye. Now then, this membrane being taken away, there are under it three proper coats belonging to the eye. The outward coat is called the *ſclerotica*, a finer coat next this is called the *choroides*, and the moſt internal of all is the *retina*, which covers chiefly the internal back part of the eye. The outward coat, or *ſclerotica*, is tranſparent, like horn, on the fore-part of the eye, and that part of it is therefore called the *cornea*, or horny-coat. The *cornea* is repreſented by D E G. The ſecond

cond coat, or *choroides*, does not line the *cornea*, as it does the other parts of the upper coat, but leaves a paſſage before for the light to enter, opening in a ſort of mouth, which is gathered or expanded by little fibres, which open it or contract it, as running ſtrings do the mouth of a purſe. Theſe fibres are called the *iris*, and may be ſeen through the tranſparent *cornea*, and they alſo give the denomination of colour to the eye. Whenever there comes too much light to the eye, the circular fibres of the *iris* contract the opening; whenever the light is rather wanted, the radial fibres of the *iris*, on every ſide, draw the hole more open. The little hole, which the *iris* thus contracts or dilates, is no other than the pupil or ſight: that little black ſpeck, which we ſee ſo ſhining in every eye, and which we know to be ſometimes larger and ſometimes leſs. The moſt internal coat is the *retina*: this lies at the back of the eye, and ſomewhat reſembles a ſpider's web.

THE coats of the eye being thus diſpoſed, the fluid within is diſtinguiſhed in the following manner. In the fore-part of the eye, juſt behind the *cornea*, lies a fine tranſparent fluid like water: it gives that protuberance to the eye on the fore-part, which was mentioned in the beginning, and fills up the cavity *m m* and *n n*. Farther backwards lies the cryſtalline humour L L, of the conſiſtence of gum arabic, and pretty much ſhaped like a ſmall horn-button mould: it ſtands with the moſt convex ſide backwards, and it is ſometimes brought forward a little by fibres, called the Ciliary Circle, which go round its edges like a hoop. Hindmoſt of all the humours lies that called the Vitreous Humour, K K, of the conſiſtence of a jelly, perfectly tranſparent, and in great quantity, filling all the back part of the eye. Now then, if we have a clear idea of the foregoing deſcription, we muſt know, that the aqueous or watery humour lies foremoſt in the eye, that the hard cryſtalline humour ſtands farther back, by being placed behind the pupil, or hole of the eye, as we would fix a glaſs behind the hole of a window-ſhutter in a darkened room. Behind this is the vitreous humour, filling the whole backward apartment of the eye. If we expoſe a ſheep's eye in an hard froſt to one night's freezing, the next morning all the humours of the eye will be frozen, and we may with a ſharp knife cut the icy globe in two parts; by which means we ſhall have the moſt diſtinct view of the three humours, as they lie within their external covering.

IF by this time the reader has ſome idea of the ſtructure of the eye, the nature and manner of viſion will be eaſily conceived. As every point of every viſible object ſends forth rays that ſtrike the eye, let us ſuppoſe a viſual ray coming from the upper point of the external object A B. This, like all rays coming from a point, will diverge and ſeparate as it goes along, and when it arrives at the *cornea* of the eye it will be ſpread upon its ſurface. Here, however, it is refracted by the aqueous humour, and thus it will be converged into a compaſs ſmall enough to paſs through the pupil, behind which it falls upon the cryſtalline humour where it is ſtill more refracted; ſo that by the time it has paſſed thence it is nearly collected into a focal point, but ſtill converging yet more as it proceeds through the vitreous humour, it will at laſt fall upon the back of the eye in a point: and thus there will be as many points formed on the back of the eye as there were viſual rays ſent from every part of the object; ſo that the whole picture of the object will be formed on the back part of the eye. The poſition, however, of the object will be inverted, the bottom rays being refracted uppermoſt and inverſely, as we more than once had occaſion to mention. The picture being thus formed, it is painted on the back part of the eye, or the retina, which is only a fine expanſion of the optic nerve, that is inſerted towards the back part of the eye. This nerve runs to the brain, and by that means all its pictures are conveyed to the common ſenſory.

IT has been a ſubject of great inquiry to aſſign the cauſe how we come to ſee every object in its natural upright poſition, when we know it to be inverted on the organ of ſenſation. How when Nature draws the picture the wrong way, we ſo readily correct her errors and place it right again, even without being conſcious of our rectitude. To ſolve this, ſome ſay that we certainly ſee every object the wrong way, but that our judgment firſt corrected the error, and habit corrects it in ſucceſſion. To correct this error at firſt, demanded an effort of the mind; but conſtant cuſtom at length grew a ſecond nature, ſo that, in a ſhort time, our corrections became mechanical and inſtantaneous.

ſtantaneous. Judgment corrects ſo often, that it forgets that it corrects at all. As the motion of a tradeſman's arms are firſt acquired by ſtudy and art, after a time he becomes inſenſible of their exerciſe, and even in his very walk, they often, againſt his will, betray his profeſſion; ſo, ſay they, we have *taught* our eyes the art of ſeeing differently from what they would in a ſtate of nature.

This is but a weak way of accounting for the cauſes of things. According to them we are under continual deceptions; how then can we truſt our judgements that what they tell us is not a deception? The truth is, if there be any real reſemblance between things and our ſenſations; as the image is inverted in paſſing through the humours of the eye, why may it not as well be again inverted in its paſſage from the optic nerve to the brain, the picture on the eye is immaterial in this conſideration; the picture on the brain or common ſenſory is all that we ſhould ſtrive to diſcover, and that may, for ought we know, be upright enough; reaſon does not contradict this, and every moment's experience confirms it.

BUT to go on with the nature of viſion. Though the three humours of the eye be requiſite in ſeeing objects diſtinctly and at the proper diſtances, yet we can ſee tolerably well, even though one of them ſhould be taken away, particularly if we aſſiſt the ſight by glaſſes. It very often happens that the cryſtalline humour loſes its tranſparency, and thus prevents the admiſſion of the viſiual rays to the back parts of the eye. This diſorder is called by the ſurgeons, a cataract. As we know that the cryſtalline humour ſtands edgeways behind the pupil, all then that we have to do, is to make it lie flat in the bottom of the eye, and it will no longer bar up the rays that come in at the pupil. A ſurgeon, therefore, takes a fine ſtraight awl, and thruſting it through the coats of the eye, he depreſſes the cryſtalline into the bottom of the eye, and there leaves it. Or ſometimes he cuts the coats of the eye, the cryſtalline and the aqueous humour burſt out together; in ſome hours the wound cloſes, a new aqueous humour returns, and the eye continues to ſee, by the means of a glaſs, without its cryſtalline humour. This operation is called couching for the cataract. Cheſelden once couched a boy who had been blind from his birth with a cataract. Being thus introduced, in a manner, to a new world, every object preſented ſomething to pleaſe, aſtoniſh, or terrify him. The moſt regular figures gave him the greateſt pleaſure, the darkeſt colours diſpleaſed, and even affrighted him. The firſt time he was reſtored, he thought he actually touched whatever he ſaw; but by degrees his experience corrected his numberleſs miſtakes.

THE eye may be remedied when the cryſtalline humour only is faulty; but when there happens to be a defect in the optic nerve L, which carries the image to the brain, then the diſorder is almoſt ever incurable. It is called the *gutta ſerena*, a diſorder in which the eye is, to all appearance, as capable of ſeeing as in the ſound ſtate; but, notwithſtanding, the perſon remains for life in utter darkneſs. The nerve is inſenſible, and ſcarce any medicine can reſtore its loſt ſenſations.

BUT though the optic nerve be thus the only conductor by which images are conveyed to the brain, yet there is an artery running through the midſt of it, upon which, if the rays from an object happen to fall, there will be no picture whatſoever formed, and the object will remain unſeen. That part of any image which falls upon the artery in the middle of the optic nerve, is entirely loſt; for arteries have no ſenſibility, and conſequently no power of perception. An eaſy experiment will ſhow this. If we fix three black patches

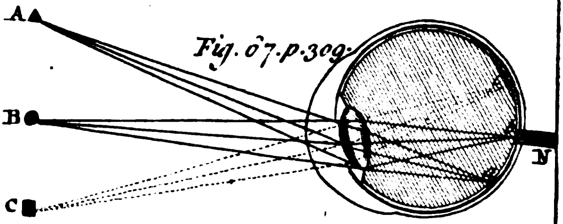


Fig. 67. p. 309.

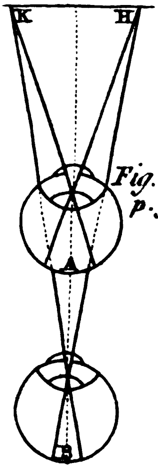


Fig. 68 p. 310.

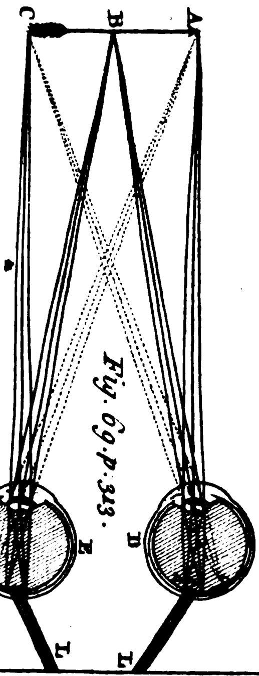


Fig. 69. p. 313.

Proud Sc.

A B C (ſee fig. 67) upon a white wall about as high as our eyes, each about a foot diſtance from each other, one to the right, one to the left, and one in the middle. Now, if the ſpectator places himſelf at a ſmall diſtance before them, and ſhuts the right eye, then directing his left towards the patch C, he will ſee the patches A and C; but the middle patch B will be covered by the artery in his optic nerve, and will therefore diſappear. Or, if he ſhuts his left eye, and directs the right towards A, he will ſee both A and C, but B will diſappear; and if he directs his eye towards B, he will ſee both B and A, but not C. Whatever patch falls under the artery is unſeen. This requires a little practice; but the ſpectator may ſoon become ſo expert, as by the direction of his eye to loſe whatever patch he thinks proper. In our ordinary intercourſe with viſible objects, we are no way ſenſible of this defect in our ſight; becauſe we turn the viſual parts of the eye with ſo much rapidity upon the inviſible part of the object. All loſſes that laſt but for an inſtant are imperceptible; each moment that the eyes twinkle we remain in utter darkneſs; the ſhort duration of our want alleviates it.

THE nearer any object is to the eye, the larger is the angle by which it will appear in the eye, and therefore the greater will be the ſeeming magnitude of that body. Nothing can be more obvious. Suppoſe the object H K (ſee fig. 68) removed at a hundred yards diſtance, it will form an angle in the eye at A. At two hundred yards diſtance, the angle it makes will be twice as little in the eye at B. Thus to whatever moderate diſtance the object is removed, the angle it forms in the eye will be proportionably leſs, and therefore the object will be diminiſhed in the ſame proportion. From this diminution of the magnitude of bodies we generally judge of their diſtance.

tance. I ſee a man upon the mountain ſide; he really appears to my eye an hundred times leſs than the child that ſtands near me. Inſtead of ſaying that the man is leſs than the child, I correct the information of the ſenſe, and ſay that the child is much nearer me than the man. However, after all, it is, at preſent, with a great ſhew of reaſon diſputed, whether theſe angles have much to do in viſion; a child one yard diſtant from the eye appears under twice the angle of a tall man four yards from the eye; yet we know that painters, whoſe buſineſs is to imitate nature, make no ſuch abrupt diminutions in perſpective; their men, though ten yards behind, are larger than their children on the foreground of the canvas. The rule of angles therefore, is not obſerved in bodies very near, nor does it make any diſtinction in the diſtances of objects very remote. The celeſtial bodies ſeem all ſtuck upon the ſame ſtarry vault, at one diſtance; the mountain's top, when far removed into cloudy perſpective, ſeems to enlarge rather than to diminiſh by its remoteneſs. The viſual angle therefore, under which a body is ſeen, will only be juſtly diminiſhed at moderately remote diſtances. Yet, after all, though the perſpective diminution of objects give us an obſcure idea of their diſtance, yet painters are obliged to call in another art to their aid, to give their figures the proper degree of remoteneſs; they ſpread over each a thick colouring of air; for the more remote the object, the more do its own colours ſeem loſt in that of the intervening atmoſphere. This is called *keeping*, for by this means every object in a picture ſeems to keep its proper diſtance from the reſt.

We have hitherto mentioned the effect of viſible objects only upon one ſingle eye, we need ſcarce repeat the proverb, that two eyes ſee better than one. In fact, by means of two we ſee more plainly, and are always better prepared, in caſe of accidents. Opticians generally preſent us with a figure, by which they ſhew the method of two eyes ſeeing the ſame body at once (ſee fig. 69). In this both eyes are turned inwards, in order to take a view of an object placed at a ſmall diſtance from them; ſo that they may be thus ſuppoſed to behold the ſame object only as one ſingle body. This figure, and the theory alſo derived from it, ſeem to me erroneous. We cannot turn our eyes both inwards or both outwards, unleſs we ſquint. For inſtance, let a perſon try to throw both eyes at once on the point of his own noſe, he will find himſelf utterly incapable of doing it. Nor do we, when turning both eyes towards the ſame object, ſee it ſingle, as this figure would repreſent, but actually double. If we firſt obſerve an object with our right eye, and mind what part of the wainſcot it correſponds with, then let us obſerve it with the left, and it will ſeem to correſpond with a different part. Then let us obſerve it with both eyes at once, and the object will ſeem in a ſituation between the two points with which it before correſponded. Thus we really ſee an image of the object to the right, and another to the left; but our judgment determines it to be but one image between both. If we preſs the globe of either eye inwards with our finger, we ſhall make that eye ſquint; and we ſhall ſee juſt in the manner as a man that ſquints naturally. But by this preſſure we ſhall find, that if we turn to any object, we ſhall ſee two images inſtead of one; whereas, the man that ſquints naturally, thinks he only ſees one ſingle image. Whence comes this difference? The truth is, he ſees two images as well as we; but he has long ſo learned to bethink right, that he forgets he was ever wrong: the miſtake is new to us, and therefore the error is obvious. All perſons, how ſtraight ſoever their eyes may be, ſee two images, juſt as a man who ſquints; but like him, they bring their other ſenſes to correct the errors of viſion. I once ſaw a diſorder where the judgment was too feeble to give laws to ſenſation. Almoſt every one of the ſenſes brought the unhappy patient its erroneous information; but I could not avoid remarking, that his ſight preſented every object to him double.

CHAP. VII.

Of the Method of aſſiſting Sight by Glaſſes.

ALMOST every eye is ſo framed as to be able to ſee diſtinctly at different diſtances rays coming from different parts of the object. To ſee objects diſtinctly, it is requiſite that each ray ſhould be diffuſed upon the *cornea*, and from thence be converged into a point, which will help to ſtipple or point out the image of the external object upon the back of the eye. On this union, or pointing of the rays upon the back of the eye, depends diſtinct viſion; for ſhould they be united before they come there, or ſhould the point where they would unite, lie farther back than the *retina*, it is evident that the ray, from each point of the external object, would thus take up too much room in the back of the eye, and mix with that next it, and that with another, and ſo all the rays would be thus mixed and blended together on the back of the eye, exhibiting together a very confuſed repreſentation of the object without.

Now, the greater the diſtance from whence rays come, the more parallel do they fall upon the eye; whence, therefore, the image of near bodies will not converge in the eye ſo ſoon as the diſtant ones; when they come from a leſs diſtance they are more widely ſcattered. The eye then muſt have a power of adapting its form to the reception of bodies at different diſtances. That is, if it is to receive the image of diſtant objects whoſe rays come parallel and converge quickly, it muſt have a power of bringing the back-part of the eye more forward to meet the focus of the convergent rays. On the contrary, if the object be very near, as the viſual rays will then converge very far back, the eye muſt have a power of lengthening its orbit, in order to let the rays fall at a proper a proper focal diſtance on the *retina* behind. All this is performed by means of ſix muſcles which are inſerted into the outward coat of the eye, which, like ſo many cords or pulleys, lengthen the eye-ball at pleaſure. So that by their means, the eye which is globular, is ſometimes lengthened nearly into the ſhape of an egg with the ſmall end foremoſt. When the object to be ſeen is very near, the muſcles act together, and lengthen the eye to make a long focal diſtance; when the object is remote, the eye reſumes its natural form, and the focal points of the diſtant rays fall upon the *retina*.

YET, notwithſtanding this contrivance of Nature to adapt our eyes to different objects at different diſtances, there are ſome eyes, in which, rays coming from diſtant objects, will not find a proper focus, and objects will be therefore confuſedly ſeen; while there are others where the rays from near objects will, by

Fig. 70 p. 319.

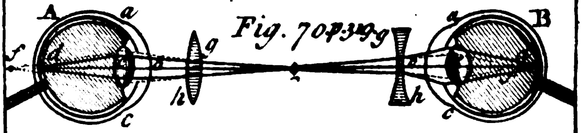


Fig. 71. p. 322.

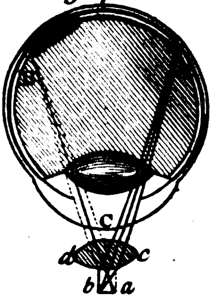
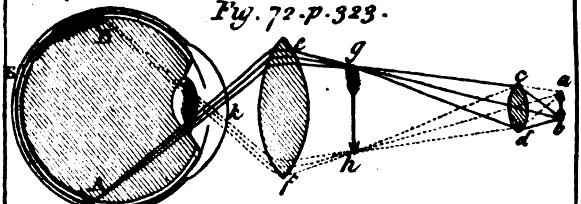


Fig. 72. p. 323.



Proud Sc.

by falling too far back into the eye, be equally confuſed. For if, in the firſt caſe, the *cornea*, or cryſtalline humour of the eye, be very convex, as in the eye B (ſee fig. 70) it will refract the rays too ſoon for diſtinct viſion. For the rays that enter it from the object C, will be converged to a focus much too ſoon, and before they come to the *retina* at *f*. Perſons thus affected, are ſaid to be near-ſighted, that is, they can ſee objects near the eye whoſe rays enter very divergent, with minute preciſion; but if the objects are removed at any conſiderable diſtance, they become confuſed and indiſtinct. If the ball of the eye has been long kept in a lengthened poſition by regarding very minute objects, it will, at length, aſſume this conſtrained form, and the perſon will become near ſighted from the elliptical figure of his eye. Thus we ſee ſeveral perſons become ſhort ſighted, when the nature of their employments obliges them to be converſant with the ſmalleſt ſubjects, as miniature painters, virtuoſi, and watchmakers. This inconvenience is remedied by uſing a concave glaſs, which always cauſes the rays to diverge; ſo that when they are made to fall diverging upon the eye, the focal diſtance is removed to the proper place, and is juſt upon the *retina*.

ON the other hand, there are eyes that require the uſe of convex glaſſes to make them ſee objects diſtinctly. For if the *cornea a b c*, or cryſtalline humour be too flat, as is uſually the caſe with the aged, they will not refract the rays ſo ſoon, wherefore their focus would fall behind the *retina*, and thus cauſe an indiſtinct impreſſion. This infirmity is remedied by uſing a convex glaſs, which converges the rays before they come to the eye, and throws them, thus converging, upon the flat *cornea*, which, thus aſſiſted, throws them exactly to the focal diſtance.

BUT there are other glaſſes which we now come to explain. The microſcope, which magnifies ſmall bodies to ſuch immenſe bulks, is an inſtrument of infinite uſe to philoſophy, ſince by it a new world is opened to the eye, of which mankind before never even ſuſpected the exiſtence. Of all thoſe who have made microſcopical diſcoveries, Leeuwenhoek deſerves the firſt place; his reſearches were generally guided by ſenſible theory, and not diffuſed at random throughout all nature. He made many microſcopical diſcoveries which have been ſince found true by repeated obſervation; he has made others, which we have adopted barely upon his authority; for neither our eyes nor our glaſſes are capable of arriving at a clear view of their minuteneſs. He left his microſcopes to the Royal Society; we have ſince made others that magnify many degrees beyond them; yet for all this, our diſcoveries fall ſhort of his obſervations. Long habit probably taught him better arts

arts of adapting his inſtruments, and fitted his eye more properly to them. The nearer any body is to the eye, the larger the angle it will be ſeen under; but then if placed too near the naked eye, the image will be confuſed and irregular. The microſcope remedies this defect; it brings the object cloſe to the eye, and yet does not hinder diſtinct viſion.

The common ſingle microſcope (ſee fig. 71) is only a ſmall and very convex glaſs, as *c d.* The object to be magnified is placed at its focal diſtance, and the eye is to be at the ſame diſtance on the other ſide. The rays flowing from every point of the object run parallel after refraction, and ſpread themſelves upon the *cornea.* From thence they are converged into as many different points on the *retina*, forming one large diſtinct picture. Large, for the object being very near is ſeen at a great angle; diſtinct, for the object's rays fall parallel upon the *cornea.* If we would know mathematically, how much a glaſs of this kind magnifies the object, geometricians ſhew that we muſt firſt find out the focal diſtance of the glaſs, that we muſt next try at what diſtance we can, with the naked eye, view the ſame object diſtinctly. Divide this laſt diſtance by the former, and the *quotient* will be the body's apparent increaſe.

THE double, or compound microſcope (ſee fig. 72) conſiſts of an object glaſs *c d*, and an eye glaſs *e f*; the object to be magnified is placed at ſomething more than the focal diſtance, by which means the rays converge after paſſing through it, and form the picture of the object a little before the eye-glaſs *e f*, and if it be properly placed, the picture ſhould be exactly in its focus. The rays diverging from this picture fall upon the eye glaſs, where they again ſuffer refraction and paſs on parallel to the eye, and will then be converged upon the *retina*,

and

and form a large inverted image AB. The magnifying power of this microſcope is as follows. Suppoſe the image *g h* to be ſix times the diſtance of the object *a b* from the object-glaſs *c d*, if ſo, it will be ſix times greater; this image may be ſeen diſtinctly, if placed within an inch of the eye-glaſs, whereas, the naked eye could not ſee it diſtinctly but at ſix inches diſtance; conſequently it will be viewed under an angle ſix times greater ſtill. So that it is increaſed ſix times ſix, which make thirty-ſix times. Its diameter will be thus magnified; its whole ſurface will be therefore increaſed by the ſquare of the diameter, that is 1296 times.

THUS we ſee, by adding one glaſs, how much the ſurface of the minute object is enlarged; a third and a fourth glaſs, if added, would magnify it ſtill more; but this addition of new glaſſes is abſolutely precluded, becauſe the more the glaſſes are increaſed, the more muſt the light be diminiſhed, and the darker will the object appear, till at laſt it be involved in utter obſcurity. Mathematical inſtrument-makers have contrived various ways of making microſcopes, and have given to each a peculiar name. There are catadioptic microſcopes, ſolar microſcopes, reflecting microſcopes, and ſo forth; the deſcription of but a part of theſe might occupy volumes, and the peruſal might be of advantage to mathematical inſtrument makers.

WHATEVER microſcopes perform upon minute bodies, very near; teleſcopes perform upon great bodies very remote; namely, they enlarge the angle in the eye under which the bodies are ſeen; and thus, by making them very large, they make them appear very near; the only difference is, that in the microſcope, the focus of the glaſſes is adapted to the inſpection of bodies very near; in the teleſcope, to ſuch as are more remote. Suppoſe a diſtant object at A B (ſee fig. 73), its rays come nearly parallel, and fall upon the convex glaſs *c d*; through this they will converge in points, and form the object E at their focus. But it is uſually ſo contrived, that this focus is alſo the focus of the other convex glaſs of the tube. The rays of each pencil, therefore, will now diverge before they ſtrike this glaſs, and will go through it parallel; but the pencils all together will croſs in its focus on the other ſide, as at *e*, and the pupil of the eye being in this focus, the image will be viewed through the glaſs, under the angle *g e h*, ſo that the object will ſeem at E under the angle D *e* C. This teleſcope inverts the image, and therefore is only proper for viewing ſuch bodies, as it is immaterial in what poſition they appear, as the ſun, the fixed ſtars, &c. By adding two glaſſes more, the image may be ſeen upright. The magnifying power of this teleſcope is found by dividing the focal diſtance of the object glaſs, by the focal

Pl.21.p.326. Vol.II.

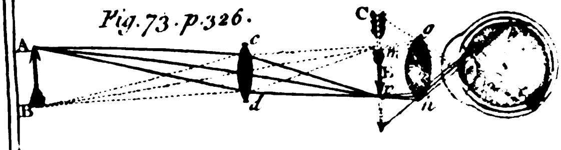


Fig.73.p.326.

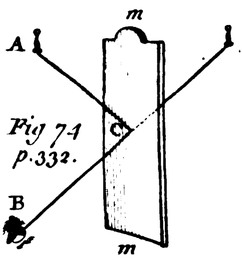


Fig 74 p.332.

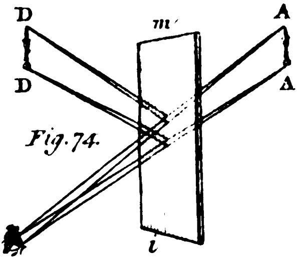


Fig.74.

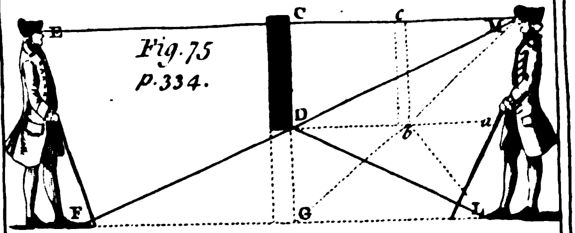


Fig.75 p.334.

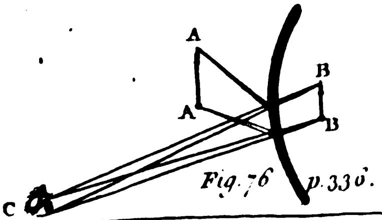


Fig.76 p.330.

Proud Sculp.

diſtance of the eye-glaſs, and the *quotient* expreſſes the magnifying power.

It is not the deſign of the preſent elementary ſyſtem, to exhibit long or accurate accounts of the whole philoſophical apparatus; the variety of teleſcopes is ſtill greater than that of microſcopes. The art of uſing theſe, or of underſtanding their conſtruction thoroughly, is beſt learned from the artificers whoſe only buſineſs is to make them. Teleſcopes have received ſome improvements ſince the beginning of this century. Thoſe they have received from Mr. Dollond, a mathematical inſtrument-maker, deſerve to be mentioned. By increaſing the number of glaſſes in the refracting teleſcope, he has made an inſtrument of this kind, but three feet long, magnify the object as much as an ordinary teleſcope of ten. It was long thought, and even demonſtration had been brought to prove, that refracting teleſcopes were incapable of farther improvement by the addition of a greater number of glaſſes. It was ſaid, that ſome rays of light were more refracted in paſſing through glaſſes than other rays; ſo that numerous glaſſes would permit only the leaſt refrangible rays to paſs on through them all to the eye; and theſe rays which had been thus ſtrong enough to get through, being but few in number, and all of one colour, they would imprint no picture. Dollond, however, diſregarding the theory, tried the experiment of adding more glaſſes, and then theoriſts began to ſay, that light was not ſo very refrangible. It is remarkable enough, that the members of the academy of Peterſburgh, propoſed the improvement of the refracting teleſcope to the learned, as a ſubject for the year's prize; the very year Dollond made this diſcovery. Dollond's improvement was yet unknown. Another received the reward, who aſſerted that the propoſed improvement was impoſſible.

CHAP. VIII.

Of Catoptrics, or of objects ſeen by being reflected from poliſhed ſurfaces.

AFTER having, as conciſely as poſſible, ſhewn the various wonders of viſion, why remote bodies appear ſmall, why glaſſes ſeemingly alter their diſtance and magnitudes; after having ſhewn how the eye itſelf is an optical machine of the fineſt contrivance, capable at once of lengthening itſelf for diſtant view, and ſhortening for microſcopic viſion; yet ſtill new wonders remain behind. How a looking-glaſs comes to reflect images, without their touching it; how the whole figure of a man ſix feet high ſhall be ſeen in a glaſs not above three feet? How when we look at ſome poliſhed ſurfaces, as a watch caſe, for inſtance, a man's face ſeems not bigger than his nail? While, if we look on other ſurfaces, the face ſhall be of gigantic ſize ; theſe are all wonders that the curious would wiſh to underſtand, and the inexperienced to examine.

BEFORE Newton expanded nature to our view, it was ſuppoſed that every ray of light which bodies reflected, rebounded from their ſurfaces, as we ſee a marble bound when ſtruck upon the pavement. Newton, however, taught mankind, that rays of light never touch the bodies from whence they are reflected; but that every ray, when it comes within a certain diſtance of the body, either paſſes entirely through, or is again ſtruck back, as we ſee filings of ſteel when brought near to the loadſtone. However poliſhed the ſurface of the ſmootheſt object may ſeem to our ſight and touch, yet it is, in fact, one continued aſſemblage of inequalities. To us theſe inequalities appear ſmall, but if compared with the ſmallneſs of light, they are as mountains. From the ſurface of ſuch, therefore, it cannot be ſup-
poſed

poſed that rays will be reflected with that uniformity we uſually obſerve; or that we could ever ſee an image of ourſelves completely reflected; for unequal ſurfaces muſt make unequal and ſcattered reflections. "If light," ſays Newton, "were reflected by ſtriking on the ſolid parts of the glaſs, it would be ſcattered as much by the moſt poliſhed glaſs as the rougheſt." We muſt be obliged to allow, therefore, that it is reflected before it arrives at the ſurface, and that the whole body, and not any ſingle point, drives it back; all the parts oppoſe their united repelling power, to meet the incurſive rays, and drive them back with uniformity.

LET us, however, for a ſhort time, ſuppoſe that every reflected ray ſtrikes againſt the body, and rebounds from it to the ſpectator's eye, like a tennis ball to the racket of a player. Now, whatever was the direction in which the ray ſtruck the body, it will rebound with a contrary direction. If I ſtrike an ivory elaſtic ball againſt the pavement, whatever force I impreſſed upon it, it will reſtore itſelf with a contrary force; and whatever direction I gave it, it will rebound in a contrary direction. If I ſtrike it perpendicularly down, it will riſe perpendicularly; if I ſtrike it in an oblique direction, it will mount obliquely the other way. This is neceſſarily the reſult of its elaſtic quality. A ray of light may be conſidered as an elaſtic body, and whatever be the angle of its incidence upon the plain ſurface, the angle of its reflection will be ſimilar. The line A C (ſee fig. 74) is the line of incidence, the line C B is the line of reflection, and theſe form equal angles on the ſurface of the poliſhed mirrour; ſo that all the rays coming from the object, and falling upon the mirrour at C, will ſtrike the eye at B, and the reflected image will thus become viſible. But now a difficulty remains. How comes it then, that we do not ſee the body at C, ſince it is there that all its rays fall; and why do we ſee it deep within, or behind the mirrour, at D? This is anſwered thus; no object can be ſeen that does not lie in a ſtraight line from the eye, or, at leaſt, appear to do ſo. The body A, therefore, when it comes reflected to the eye, will appear to lie in the ſtraight line B D, which, ſince the angle of incidence is equal to that of reflection, will be exactly in the two lines A C and A B. The rays, therefore, going from A to C, will be ſeen at D, and conſequently, ſo will the picture. For, as the rays have diverged in going from the object at A A, and diffuſed themſelves upon the ſurface of the glaſs, they will be again converged into an equal focus, by the time they arrive at D D, and they will therefore paint the object at D D.

FROM hence we may learn, that if a man ſees his whole image in a plain looking-glaſs, the part of the glaſs that reflects his image, is but one half as long and one half as broad as the man. For the image is ſeen, under an angle, as large as the life; the reflecting mirrour is exactly half-way between the image and the eye, and therefore muſt make but an angle half as large as the image, or in other words, it is juſt half as large as the image which is of the ſame ſize with the man. Thus the man A B (ſee fig. 75) will ſee the whole of his own image in the glaſs C D, which is but half as large as himſelf. His eye, at A, will ſee the eye of the image at an equal diſtance behind the glaſs at E. His foot at B will ſend its ray to D; this will be reflected at an equal angle, and the ray will therefore go in the direction of F D A; ſo that the man will ſee his foot at F. That is, he will ſee his whole figure E F. But ſuppoſe his foot was lower than B at L, then he could not ſee it; for the ray L ſtriking the glaſs at D, would be reflected with an equal angle up to M, far above the man's eye, and cononſequently out of his ſight. In the ame manner as he advances or retires, e will ſtill ſee his own image, if all he lines of reflection come to his eye ; ut if they riſe above it, like D M, or all below it, that part of the object, to im, will be inviſible, though another pectator at M may ſee his feet at L, which he himſelf cannot ſee.

Thus plain mirrours reflect, not only he object, but the diſtance alſo, and that xactly in its natural dimenſions; but it s otherwiſe with regard to convex mirours, ſuch, for inſtance, as a watch-caſe, which diminiſh; or concave mirrours, which, on the contrary, magnify it. As o convex mirrours, the nearer we approach them, the more the image ſtarts back; in the caſe of concave, as we draw near them, the image ſeems to ſtep forward, beyond the glaſs, to meet us.

To ſhow firſt, how images are leſſened in the convex mirrour, we muſt ſtill repeat the former rule, that the angle of reflection is ever equal to the angle of incidence. Carrying this in our memory, let us ſuppoſe (fig. 76) an object A A is reflected by a convex glaſs, to the eye, at C. Let us conſider, at what angles each pencil of rays, from the object, will fall upon this convex ſurface. It is certain, that each angle which they make with it, will be more acute than if the mirrour's ſurface were perfectly flat. If ſo, after reflection, the reflected rays being ſuppoſed to paſs onward to B, they will be converged much ſooner from acute, than if they came from large angles; and the object B B will therefore appear more near and ſmaller than the life.

On the other hand, with regard to concave mirrours, an object muſt appear in them larger than the life, if it be placed moderately near (ſee fig. 77). For the pencil of rays B B falling at larger angles upon the concave ſurface, if they are reflected; they will not converge

Pl.22 .p.336. Vol.II.

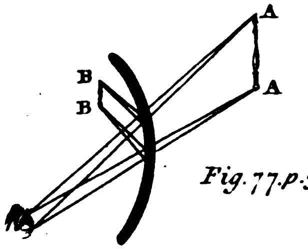
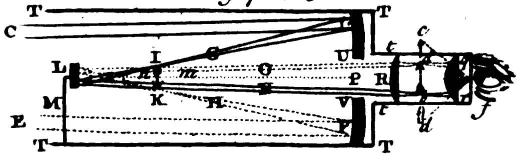


Fig. 77. p. 336.

Fig. 78. p. 340.



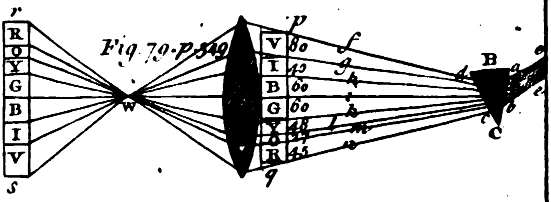


Fig. 79. p. 349.

Proud Sculp.

verge ſo ſoon, and not till they apparently come to the greater diſtance A A. They will therefore, be ſeen at A A. But A A is larger and more diſtant from the glaſs than the real object B B, and therefore it is apparently magnified.

As the real principles of catoptrics are perfectly mathematical, and can be known only by thoſe who are verſed in deep geometry; it would be vain to attempt leading the reader farther into this ſubject, as every ſtep onward would be found to increaſe the gloom. The principles of this ſcience, particularly with regard to the places where objects are ſeen in mirrours, are yet in diſpute among mathematicians, and hitherto undecided. Newton acknowledges the determination of the apparent place of an object, ſeen in a concave mirrour, to be the moſt difficult part of all mathematics. His words are, *Puncti illius accurata determinatio, problema ſolutu difficillimum præbebit, niſi hypotheſi alicui ſaltem veri-*

ſimili,

ſimili, ſi non acurate veræ, nitatur aſſertio. The ſolutions of ſuch problems will be immenſely difficult, unleſs we take the probability of conjecture to ground aſſertion on.

THERE are ſeveral amuſing optical deceptions which are effected by a proper combination of plain or convex mirrours. We all know, that if a man ſtands with his face oppoſite a looking-glaſs, and with his back to another, he will ſee his figure many times reflected. If an hexagon chamber, (one with ſix ſides) be ſo contrived as to have light admitted, in ſufficient abundance, from the top, and a large glaſs on every ſide, a man ſtanding in this chamber, will ſee himſelf multiplied into a ſeeming crowd. The effect is ſtill more pleaſing by candle light.

LET there be a box of ſix ſides, and divide its inſide by as many little partitions running from each corner, which will all conſequently unite in the middle. Line each partition with looking glaſſes, and let there be an hole made on every ſide of the box to look through. Cover theſe holes with plain glaſs, and cover the top of the machine, thus prepared, with fine oiled parchment, and the catoptric box is made. Whatever object we place upon the ſide or ſides, at which we look in, it will be multiplied in the moſt pleaſing manner, and by turning different ſides, a variety of proſpects may be thus offered to the view, each ſeemingly twenty times larger than the capacity of the machine we look through.

In another box, if we uſe a convex glaſs, ſuch as we uſually read with, at a hole on the ſide of the box, and place a looking glaſs in its focus, in ſuch a manner, that while the focus falls upon the mirrour, the mirrour at the ſame time reflects objects or pictures below; this will magnify thoſe pictures very much, and place them ſeemingly at a great diſtance from the eye. Theſe may amuſe the youthful; but there have been catoptric inſtruments formed for the amuſement of philoſophers. The reflecting teleſcope is among the number. This inſtrument was firſt invented by Newton, who ſaw the inconvenience of uſing very long refracting teleſcopes, and therefore ſubſtituted reflectors. He gave directions for making one of ſix inches long, which was found to magnify objects as much as a common refractor of four feet. If any reader deſires to know the conſtruction of this inſtrument, he ſhall have it from Mr. Ferguſon's deſcription, which is the plaineſt that I have met with.

"AT the bottom of the great tube T T T T (ſee fig. 78) is placed a large concave mirrour D U V F, whoſe principal focus is at *m*; and in the middle of this mirrour is a round hole P, oppoſite to which is placed the ſmall mirrour L concave toward the great one, and ſo fixed to a ſtrong wire M, that it may be removed further from the great mirrour, or nearer to it, by means of a long ſcrew on the outſide of the tube, keeping its axis ſtill in the ſame line P *m n* with that of the great one. Now, ſince in viewing a very remote object, we can ſcarce ſee a point of it, but what is, at leaſt, as broad as the great mirrour; we may conſider the rays of each pencil which flow from every point of the object, to be parallel to each other, and to cover the whole reflecting ſurface D U V F. But to avoid confuſion in the figure, we ſhall only draw two rays of a pencil flowing from each extremity of the object into the great tube, and trace their progreſs through all their reflections and refractions to the eye *f* at the end of the ſmall tube *t t*, which is joined to the great one.

" LET us then ſupppoſe the object A B to be at ſuch a diſtance, that the rays C may flow from its lower extremity B, and the rays E from its upper extremity A; then the rays C falling parallel upon the great mirrour at D, will be thence reflected converging in the direction D G, and by croſſing at I in the principal focus of the mirrour, they will form the upper extremity I of the inverted image I K ſimilar to the lower extremity B of the object A B, and paſſing on to the concave mirrour L, (whoſe focus is at *n*) they will fall upon it at *g*, and be from thence reflected, converging in the direction *g* N, becauſe *g m* is ſhorter than *g n*, and paſſing through the hole P in the large mirrour, they would meet ſomewhere about *r*, and form the lower extremity *b* of the erect image *a b* ſimilar to the lower extremity B of the object A B. But by paſſing through the plano-convex glaſs R in their way, they form that extremity of the image at *b*. In like manner, the rays E, which come from the top of the object A B, and fall parallel upon the great mirrour at F, are thence reflected converging to its focus, where they form the lower extremity K of the inverted image I K ſimilar to the upper extremity A of the object A B, and thence paſſing on to the ſmall mirrour L, and falling upon it at *b*, they are thence reflected in the converging ſtate *b* O, and going on through the hole P of the great mirrour, they would meet ſomewhere about *q*, and form there the upper extremity *a* of the erect image *a b* ſimilar to the upper extremity A of the object A B. But by paſſing through the convex glaſs R in their way, they meet and croſs ſooner, as at *a*, where that point of the erect image is formed. The like being underſtood of all thoſe rays which flow from the intermediate points of the object between A and B, and enter the tube T T, all the intermediate points of the image between *a* and *b* will be formed. And the rays paſſing on from the image through the eye-glaſs S, and through a ſmall hole *e* in the end of the leſſer tube *t t*, they enter the eye *f*, which ſees the image *a b* by means of the large eye-glaſs under the large angle *c e d*, and magnified in length under that angle from *c* to *d*.

" In the beſt reflecting teleſcopes, the focus of the ſmall mirrour is never coincident with the focus *m* of the great one, where the firſt image I K is formed, but a little beyond it (with reſpect to the eye) as at *n*. The conſequence of which is, that the rays of the pencils will not be parallel after reflection from the ſmall mirrour, but converge ſo as to meet in points about *q*, *e*, *r*, where they would form a larger upright image than *a b*, if the glaſs R were not in their way; and this image might be viewed by means of a ſingle eye-glaſs properly placed between the image and the eye; but then the field of view would be leſs, and conſequently not ſo pleaſant, for which reaſon the glaſs R is ſtill retained to enlarge the ſcope or area of the field.

To find the magnifying power of this teleſcope, multiply the focal diſtance of the great mirrour by the diſtance of the ſmall mirrour from the image next the eye, and multiply the focal diſtance of the ſmall mirrour by the focal diſtance of the eye-glaſs; then divide the product of the former multiplication by that of the latter, and the quotient will expreſs the magnifying power."

CHAP IX.

Of Colours.

WE have hitherto conſidered light as a body uncompounded and of parts reſembling each other; but we are now going to examine its texture more cloſely: we ſhall now ſee that this fluid, though ſo ſimple to all appearance, is made up of very different particles; that it is compoſed of different coloured tints, and that from the nature of this compoſition ariſes that charming variety of ſhades which paint the face of Nature.

WHATEVER pleaſures we derive from the beauty of colouring is owing to the different rays of light alone; for the objects themſelves have no difference in this reſpect at all: the bluſhing beauties of the roſe, or the modeſt blue of the violet, are not in the flowers themſelves, but in the light that adorns them: odour, ſoftneſs,

neſs, and beauty of figure are their own; but it is light alone that dreſſes them up in thoſe robes which ſhame the monarch's glory. Take away all light and their colour will vaniſh; let but a portion of light be permitted to ſhine upon them, and their colours will be changed. But though the colours be in the light, and not in the objects, yet it is in our power to alter them at pleaſure; we have only to change the ſurface of the object, and light inſtantly gives it another colouring. Thus in every circumſtance we at beſt reſemble thoſe ſervants of painters who prepare the frame or ſtretch the canvas, but it is light alone that always holds the pencil.

THERE is a common experiment, and eaſily performed, to prove that the colours are not in the objects themſelves, but in the rays of light that fall upon them; and that if the nature of light be altered, the colours alſo will receive alterations: Let a pint of common ſpirits, the cheapeſt will anſwer as well as the beſt, a pint of malt ſpirits then, be poured into a ſoop-diſh, and then ſet on fire: as it begins to blaze, let the ſpectators ſtand round the table, and let one of them throw an handful of ſalt into the burning ſpirits, ſtill keeping it ſtirring with a ſpoon. Let ſeveral handfuls of ſalt be thus ſucceſſively thrown in; the ſpectators will ſee each other frightfully changed, their colours being altered into a ghaſtly blackneſs. Were the ſolar flame of the ſame nature with that of this compoſition, we ſhould have no other colours in nature but ſuch as thoſe produced by the experiment.

NATURALISTS were formerly of opinion that the ſolar light was ſimple and uniform, without any difference or variety in its parts, and that the different colours of objects were made by refraction, reflexion, or ſhadows. But Newton taught them the errors of their former opinions; he ſhewed them to diſſect a ſingle ray of light with the minuteſt precifion, and demonſtrated that every ray was itſelf a compoſition of ſeveral rays, all of different colours, each of which when ſeparate held to its own nature, ſimple and unchanged by every experiment that could be tried upon it.

To prove all this, it was neceſſary firſt to find out a method of ſplitting a ſingle ray of light into the ſeveral rays of which it was compoſed, and this was effected by means of the priſm, or a three ſquare glaſs already deſcribed. Let the ſun ſhine into a dark room through a ſmall hole as at *e e* in a window-ſhutter (See fig. 79.) and place a priſm B C, which we ſee endways in the figure, in the beam of rays A, in ſuch a manner, that the rays may fall obliquely on one of the ſides *a b* C of the priſm. We ſhall then ſee the rays that paſs through the priſm ſtruck upon the oppoſite wall, ranged one above the other, violet, indigo, blue, green, yellow, orange, red. The range will be beautiful, and the colours ſo bright as to exceed the power of art to equal. In this manner then is the ſolar beam ſeparated into the colours of which it is in nature compoſed; and one ray conſiſts of many rays, each different in its colour, and darting forward from the great luminary with different force. The red ray, for inſtance, goes forward more forcibly than any of the reſt, and is therefore leaſt refracted or bent out of its rectilineal courſe, but falls upon the wall almoſt in a ſtraight line at R. In proportion as each ſucceeding ray has leſs force, it is driven more out of its rectilinear direction, till at the violet it feebly paints itſelf upon the higheſt part of the picture.

THUS we ſee that in nature the brighteſt colours drive forward from the ſun with the greateſt force; and what we find true by experiment, is confirmed by our ſenſations. The brighteſt colours ſtrike our eyes with the greateſt force;

the red makes ſtrong impreſſions, the orange is not ſo forceful; the colours ſtrike us leſs vividly in ſucceſſion till we come to the violet; which approaches very near to black, and gives us a faint idea of darkneſs. For this reaſon it is, that when the eye is very weak, a ſcarlet colour becomes inſupportable, its impreſſions are too powerful, and next to the ſolar beam itſelf, dazzles and diſturbs the organ. Surgeons in this caſe generally preſcribe a black object to be placed before the eye, as a piece of black ſilk, for inſtance; but violet is very near approaching to blackneſs, ſo that that would do almoſt as well.

We now therefore may conclude, that a ſingle ray of light, which before ſeparation ſeemed to be of an uniform white appearance, is compoſed of a bundle of no leſs than ſeven different rays, and that when an object reflects them all, it then appears white. On the contrary, if the object ſends back no rays to our eye, it then appears black, which is nothing more than the privation of all colour. If we could find an object perfectly black, ſuch a body would be to us perfectly inviſible; ſuch however is not to be found in nature; and painters in drawing black objects are forced to heighten all the ground with white: and it is ſo in nature; the black which we ſee is an aſſemblage of different colours, and faintly reflecting rays of almoſt every kind. Should it be doubted that white is but the aſſemblage of all the colours of the priſm united, numberleſs experiments can be eaſily brought to confirm it. The rays, when divided by a priſm, if they be again united by a common convex glaſs, will throw a bright ſpot of white upon the ſame paper, where before they ſeparately painted the beautiful priſmatic variety. If a round board be painted with colours, imitating thoſe from the priſm, and if it be then turned ſwiftly with a circular motion, ſo as that the eye cannot have time to view any one of the colours diſtinctly,

diſtinctly; as it takes in the whole aſſemblage together, the figures on the board will reflect every colour, and appear white or nearly approaching to whiteneſs.

THESE colours, reflected by the priſm, are not only the moſt beautiful in nature, but alſo each in itſelf continues ſeparate and unalterable. When one of thoſe primitive rays has been ſeparated from the reſt, nothing can change its colour. Send it through another priſm, expoſe it in the eye of a burning-glaſs, yet ſtill its colour continues unaltered; the red ray will preſerve its crimſon, and the violet its purple beauty; whatever object falls under any of them, ſoon gives up its own colour, though never ſo vivid, to aſſume that of the priſmatic ray. Place a thread of ſcarlet ſilk under the violet-making ray, the ray continues unaltered, but the ſilk inſtantly becomes purple. Place an object that is blue under a yellow ray, the object immediately aſſumes the radial colour. In ſhort, no art can alter the colour of a ſeparated ray; it gives its tint to every object, but will aſſume none from any; neither reflexion, refraction, nor any other means can make it forego its natural hue; like gold, it may be tried by every experiment, but it will ſtill come forth the ſame.

IN whatever manner we conſider the colour of a ſingle priſmatic ray, we ſhall have new cauſe to admire the beauties of nature. Whatever compoſitions of colouring we form, if examined with a microſcope, they will appear a rude heap of different colours unequally mixed. If by joining, for inſtance, a blue with a yellow, we make the common green, it will appear to the naked eye moderately beautiful; but when we regard it with microſcopic attention, it ſeems a confuſed maſs of yellow and blue parts, each particle reflecting but one ſeparate colour: but very different is the colour of a priſmatic ray; no art can make one of equal brightneſs, and the more cloſely we examine

mine it, the more ſimple it appears. To magnify the parts of this colour is but to increaſe its beauty.

AMIDST all the variety therefore in nature, there are but ſeven original colours; violet, indigo, blue, green, yellow, orange, and red. Of theſe ſimple colours, all the artificial ones, which we ſee every inſtant, are compoſed, and every object is of this or that colour, as its parts are fitted for reflecting the correſpondent ray in greater abundance. A red object reflects the red rays moſt copiouſly, a blue object the blue, green objects reflect the green ray, and ſo of all the reſt.

BUT though the colour of an object ariſes from its reflecting rays only of one particular colour, yet a number of parts may be ſo mixed in one object, as to reflect the rays of almoſt every colour in the priſm, as we may eaſily effect by mixing different powders together, tho' in this caſe, in reality, the colours are reflected from a great number of minute objects all of different hues, yet to our naked and undiſtinguiſhing eyes, the whole ſeems but one uniform ſurface of colouring. Thus we often call that green, which is in fact a mixture of blue and yellow; we think that orange, which is compoſed of two colours, yellow and red: and thus in general objects of different tints are made to imitate one of the original tints, granted by the ſimple priſmatic ray; but colours, thus compounded, may be eaſily diſtinguiſhed from the ſimple ones. That body, which reflects one priſmatic colour in greateſt abundance, has ever the moſt beautiful and the brighteſt dye; while, on the contrary, thoſe bodies, which reflect ſeveral different colours, ſeemingly blended to the eye, ever ſtrike us with leſs vivid and leſs beautiful impreſſions: and indeed, the whole ſecret in the painter and dyer's art, is to make their colours as ſimple as they can; for in proportion as they are mixed, they loſe their beauty; for inſtance, the ſimple green priſmatic colour is the moſt beautiful imaginable; a green leſs beautiful is made by an artificial mixture of two colours, blue and yellow; a green, ſtill leſs beautiful, may be made by a mixture of ſimple green, orange, and indigo; but the moſt obſcure green of all will be that made by a ſtill greater number of theſe colours united. By much compoſition in this manner, the beauty of every colour may be deſtroyed, and all its livelineſs dimmed into faintneſs. Grey, ruſſet, brown, are only compoſitions of many colours, they may be conſidered as ſo many leſſer degrees of white, and differ only in having the proportion of their colours leſs evenly mixed, and conſequently not affecting us with ſuch ſtrong ſenſations.

IT was obſerved in the beginning, that the different colours paſſed through the priſm in different directions. The red, being leaſt refracted or bent in its courſe, went almoſt directly forward; the ſucceeding colours diminiſhed in their force, till the violet was refracted moſt of all, and went through the priſm in a very oblique direction. What can be the cauſe of this more direct progreſs in one ray than in the other? Why is the violet driven more out of its courſe than the red? Can it be aſcribed to any other cauſe than the different attractions which the different rays undergo from the medium, or glaſſy body, through which they paſs? It muſt certainly be ſo. The red rays are leaſt attracted, and therefore drive through moſt directly; the violet are moſt attracted, and therefore they go through the moſt oblique of all. We have often had occaſion to obſerve, that almoſt all bodies repel as well as attract; and that when at a certain diſtance, the attracting power is too feeble to act, then the repulſive power exerts its force, and the bodies are driven ſeparate. Now whatever be the attractive force of the priſm upon ſome rays of light in ſome circumſtances, it will have a repulſive force upon the ſame rays in other circumſtances, and that ray which it attracted moſt ſtrongly at one time, it will repel with the greateſt violence at another. A ray repelled or driven back is only in other words a ray reflected, ſo that we may ſay, that thoſe rays, which are moſt ſtrongly refracted, are moſt ſtrongly reflected alſo; the attractive power operates at one time and refracts the ray, and the repellent power at another, and reflects it. If this then be the caſe, the violet ray, as it is moſt refracted, will be moſt reflected alſo; while on the other hand, the red ray, as being ſmall in refraction, will be ſlow in reflection; and this is found true by experiment: for if we turn a priſm round upon itſelf in ſuch a manner, that the light, which was tranſmitted through it, be reflected upon an object properly diſpoſed, we ſhall ſee the violet will be the firſt colour that will ſuffer reflexion, then each other colour in ſucceſſion, till red comes to cloſe up the rear. From hence therefore we may conclude, that the ſame cauſe, which produces the refraction of the rays, produces their reflexion alſo. The more we know of Nature, the more we diſcover her uniformity.

WE may now then univerſally conclude, that if colours have not that variety, the uninitiated obſerver would ſuppoſe, that they are but few, beautiful, and ſimple, yet ſtill enough by their variety to give us all thoſe pleaſures which a mixture of them is ſometimes apt to produce. Colours and ſounds have ſomething in them alike. There are ſeven notes in muſic, there are ſo many colours in the priſm. The diſtance between each note is aſcertained, a ſimilar diſtance is alſo found between each coloured ray; but we muſt not from hence ſuppoſe that there is any real reſemblance between ſounds and colours; theſe are merely accidental ſimilitudes, and their diverſities are ſtill more numerous; each note, for inſtance, may be divided into many tones; each ſimple colour is indiviſible. The combination of tones ſometimes increaſes their beauty, on the contrary, the combination of colours deadens their effect. The ſucceſſion of ſounds have a very fine influence upon the mind, the ſucceſſion of colours has ſcarce any; yet in this philoſophical age, it was not to be ſuppoſed, that the trifling reſemblance between ſounds and colours, as mentioned above, ſhould paſs without proper notice. In fact, a whimſical French philoſopher has written a treatiſe to prove, that as our ear finds pleaſure in the ſucceſſion of ſounds, ſo the eye may have a ſimilar one from the ſucceſſion of colours. There is, ſays F. Caſtel, a muſic of colours as well as of ſounds; and when the eye has been for a ſhort time leſſoned to ocular ſucceſſion, there will ariſe as much pleaſure to the eye, as the ear derives from ſound. For this purpoſe he compoſed an ocular harpſichord, as he called it, which, inſtead of ſounding to the ear, preſented colours to the eye: the priſmatic rays furniſhed the notes, and the ſhades between were ſubſtituted for the ſemitones. The inventor however died without finiſhing an inſtrument, which raiſed the expectations of many, but excited the ridicule of more. Sounds furniſh the ear with all its pleaſure. Colours furniſh the eye but with half its pleaſures, for figure comes in for the other half. To make ſuch an inſtrument ſatisfy the ſenſe, the beauty of colour and figure muſt be united.

CHAP. X.

Of the Figure and Diſpoſition of the Surfaces of Bodies, to reflect their reſpective Colours.

THE reader now perceives the cauſe of all colours, and knows that it is light, which, differently coloured itſelf, thus dreſſes them in various beauty. Each object ſends back to our eye thoſe rays of light, which its ſurface is beſt adapted to reflect. The ruby drinks up every other ray of light, the green, the blue, and the violet, but repels back the reddening rays to our eye in all their priſmatic luſtre. The amethyſt imbibes the ſtronger rays, and gives back the violet with milder brightneſs. The tulip gives us only the yellow, and the hyacinth its vivid blue. Every coloured object may be thus regarded as a partial divider of the rays of light, as a priſm which can only ſeparate one colour, but confounds all the reſt.

IT will be now a ſubject entirely curious, to inquire what is the peculiar conformation of thoſe bodies, which thus reflect one ſort of rays and no other; to aſſign the cauſe why the ruby reflects nothing but the red rays, and the hyacinth only blue.

WE have hitherto only obſerved the colouring ſubſtance itſelf, we ought now to conſider the preparation of the ground which receives it: to inquire how it comes that every object hath this ſeparative power over the particles of light; how it imbibes one colour, while it copiouſly reflects another?

THE reaſon in general, why bodies reflect this or that kind of ray more copiouſly than any other, and conſequently aſſume one particular colour, is, that the ſize and denſity of the parts, of which bodies are compoſed, are different. Let us for a moment ſuppoſe the ſurfaces of all the objects around us compoſed of an infinite number of ſmall glaſſy plates, let us ſuppoſe too the plates of one ſurface ſomething thicker than the plates of another; let us ſtill farther ſuppoſe, that a beam of light, with all its ſeven rays, ſtrikes againſt one of theſe little thin plates, what will be the conſequence? This plate will in ſome meaſure reſemble a ſhield: if it be extremely thin, it will be unable to repel the ſtrongeſt darting rays. The red, the orange, the yellow, the green, the blue, and the indigo rays will all dart through it with unreſiſted force; the feeble violet ray alone will be unable to get entrance, and will therefore be reflected back to our eye, and we ſhall ſee the whole object, if it be compoſed of ſimilar plates, of a beautiful violet colour, while all the other rays have paſſed into the ſubſtance of the body, and are there ſtifled and loſt. Suppoſe the plate againſt which the ſeven rays are darted to be a little thicker, the indigo then will be repelled and reflected, and the object will appear of that colour; thus, as the plates increaſe in thickneſs, the colour will approach to redneſs, for the thickeſt plates of all will reflect only that colour; thus therefore the colours of bodies will depend upon the different thickneſs of the plates, of which their ſubſtance is compoſed. The thinner the plates, the body will be more inclining to violet; on the contrary, the thicker they are, it will then approach more nearly to redneſs.

BUT we have here ſuppoſed two things, which muſt be firſt proved. We have ſaid that bodies are compoſed of ſmall tranſparent plates, and we have aſſerted alſo that the thinner the plate, the more approaching to violet will be the colour. The firſt of theſe is obviouſly true, the parts of all bodies, though ſeemingly void of tranſparency, when viewed in the groſs, will be found, if taken ſeparately, to be pellucid like glaſs. Nothing can ſeemingly be more opake and free from tranſparency than the clothes we wear, yet let us but examine any one of the woollen hairs that go into their compoſition with a microſcope, and it will be found nearly tranſparent. Gold in the maſs lets no light through it, but if beaten out extremely thin, we ſhall then ſee that its parts are tranſparent like other bodies, and it will caſt a greeniſh light if put over a hole in a darkened window; ſo that if gold be compoſed of tranſparent parts, we may ſafely conclude the ſame of all other bodies whatever.

THE ſecond aſſertion, that the thinner the plates, the more inclining to violet or to black itſelf, would be the colour of the body which they compoſed, comes next in view. This, at firſt ſight, ſeems impoſſible to be proved, for where ſhall we find plates ſufficiently thin to determine this, or how can we meaſure them when found? Newton, the moſt fertile of all philoſophers in expedients to confirm his theory, threw light upon the intricacy by a very obvious, though till then unregarded experiment. The bubbles which children blow with a mixture of ſoap and water, or the froth that we often ſee ſtanding upon the ſurface of a waſhing-tub, appeared to him capable of being turned to philoſophical purpoſes; things overlooked by the reſt of mankind are often the moſt fertile in ſuggeſting hints. He blew up a large bubble from a ſtrong mixture of ſoap and water, and ſet himſelf attentively to conſider the different changes of colour it underwent from its enlargement to its diſſolution. He in general perceived that the thinner the plate of water which compoſed the ſides of the bubble, the more it reflected the violet-coloured ray; and that in proportion as the ſides of the bubble were more thick and denſe, the more they reflected the red; he therefore was induced to believe, that the colours of all bodies proceeded from the thickneſs and denſity of all the little tranſparent plates of which they are compoſed: but this was only conjecture; to bring the theory to greater certainty, it was neceſſary to meaſure the thickneſs of the plate of water which compoſed the bubble; but this was attended with ſome difficulty, for the bubble was itſelf of too tranſient a nature to admit of any experiments upon it. He now bethought himſelf therefore, that two glaſs plates might be made to approach ſo very cloſe to each other, that if water were put between them, it could be preſſed as thin as might be thought proper. For this purpoſe therefore, a glaſs, a very little convex, was placed upon a plain glaſs, by which means they touched only in the middle, while all the other parts were almoſt, but not quite touching, ſo that water, or even common air, being placed between them, was preſſed to the greateſt conceivable degree of minuteneſs. As the convexity of one of the glaſſes was known, their diſtance from each other at every point could be eaſily meaſured, and thus the thickneſs of the plate of water between them, at any diſtance from the center, where the glaſſes touched, might be determined with the moſt exact preciſion. When theſe glaſſes then were thus preſſed together, the water or air between exhibited the following appearances: In the middle point, where they touch, appeared a black ſpot perfectly tranſparent, next to this a ring of blue, then of white, yellow, orange, red; then a new order of the ſame colours begins again, and ſoon, one coloured ring without the other, for ſix or ſeven different repetitions of orders ſucceſſively, each outer circle however more obſcure than thoſe within, like the circular waves upon a diſturbed ſheet of water. In all the orders, however, it appears that the reds are reflected by the plates of greateſt thickneſs, and the violets by the thinneſt.

IT muſt be obſerved, however, that the colours in theſe rings are by no means ſimple, but made up of two or three, and ſometimes four of the ſimple priſmatic colours united together; and from hence therefore we may infer, that all the objects of nature may be ſuppoſed to have their tints compounded. Like theſe coloured rings, each object around us partakes of ſeveral ſimple colours blended into one compoſition, and by knowing the ſimple colours that go into the compoſition of a ſingle ring, we may nearly conjecture the ſimple colours, that go into the compoſition of objects of exactly ſimilar colours, with which we are ordinarily converſant. Thus, for inſtance, if we turn our eyes to the azure blue of the ſkies, and demand what are the ſimple colours that go into its compoſition, we have only to examine the different orders of blue in the variouſly coloured rings of this pleaſing experiment: among the number, we find a beautiful faint blue of the firſt order, exactly reſembling the colour of the ſerene ſky: nor does it only reſemble this blue in colour, but in nature alſo. The colour of the heavens muſt ariſe from the nearly tranſparent vapours that float within its boſom exceſſively ſmall, and their parts of almoſt inconceivable thinneſs; the blue coloured ring is reflected by a plate as thin as can well be imagined, being nearly an hundred thouſand times thinner than the cryſtal of a watch. In this manner we may find the ſimple priſmatic tints in every other object. The beautiful green of the fields exactly reſembles a fine green in one of the coloured rings of the third order. This colour is compounded of three ſimple tints, blue, yellow, and green, and reſembles the natural verdure of the fields in more than one circumſtance; for as the vegetables wither, they grow yellow, and thus diſcover the colours which originally went into the compoſition of their natural beauty; in ſhort, there is ſcarce a colour in nature, that we ſhall not find ſome ſhade in theſe coloured rings bearing ſome reſemblance to; and univerſally, the leſs compounded every colour, and the more it approaches priſmatic ſimplicity, the more vivid its appearance, and the more intenſe its ray.

Let us again therefore repeat with unſatiated pleaſure thoſe ſurpriſing diſquiſitions into nature. Every object takes its colour from the rays of light, which its parts are moſt fitted to reflect. The ſmall conſtituent parts of every object are in themſelves tranſparent, and while they ſuffer ſome rays to paſs, they reflect others. If the parts were extremely ſmall, and compoſed of plates as thin as the ſides of a bubble juſt going to break, their colour would be of the violet kind; if the parts were thicker, they would aſſume ſtronger colours through the ſucceſſive ſhades up to red. Nature however preſents us with no object, whoſe colour is ſimple and reflects only the light of a ſingle coloured ray. The ſkies, the fields, the flowers, the emerald, and the ruby all have their tints from a compoſition of ſimple colouring, each moſt beautiful the nearer it approaches ſimplicity.

Thus far of the cauſe of colour and the ſize in the parts of bodies to reflect it; but ſtill a difficulty remains: How comes it that ſome bodies are tranſparent, while others of the ſame colour are perfectly dark, and let no rays of light paſs through them? How is it that the ruby may be ſeen through, while a piece of ſealing-wax is perfectly opake? How comes it that the emerald lets the green ray, which falls upon one of its ſides, dart through to the other, while the leaf of a plant lets no light paſs through at all? In order to ſolve this queſtion, it may be proper to aſk another: If the ruby or the emerald were taken and ground into a powder, what would be the conſequence? the conſequence would certainly be, that neither would any longer be tranſparent, nor ſuffer the light to paſs through them. The ruby thus powdered and made up into a paſte, would be as opake as the ſealing-wax itſelf. The reaſon of this difference then will now be obvious: While the ruby was in its jewel ſtate, its pores were ſmall, and the plates of which it was compoſed lay evenly ſurface over ſurface, like one glaſs plate laid upon another. The light therefore falling upon this even ſolid ſurface was attracted through without hindrance, and but few of its rays were driven back, or ſuffered reflection by the way; but it muſt be very different with the ſame body when reduced to powder; it then becomes porous, its ſurfaces lie confuſed and in unequal directions. A part of the rays of light therefore will fall upon the outward broken particles of the gem, and by being reflected to the eye, give us, as in the former caſe, a ſenſation of redneſs; but far the greater number of rays will paſs into its ſubſtance, they will upon entrance find it porous, the condenſed matter which in the former caſe attracted it, and increaſed the rays celerity, now no longer acts with equal force, the ray feebly attracted therefore will be partly repelled, will dart from pore to pore, will be driven into ten thouſand directions, and will be at laſt totally loſt to ſenſe. In a word, the tranſparency of all bodies ariſes from the cloſeneſs and ſimilitude in the contexture of their parts, while their opacity on the contrary ariſes from their being very porous, or from being compoſed of parts very diſſimilar to each other. The ruby was deprived of its tranſparency by being ground to a coarſe powder, a degree of tranſparence might again be reſtored by grinding theſe coarſe parts ſo as to make them extremely fine, and thus reſtore them in ſome meaſure to their original minuteneſs. And in this manner ſome of thoſe tranſparent bodies, called paſte, are formed by repeated trituration. We may conclude therefore that to make almoſt any body tranſparent, little more is requiſite than to diminiſh the pores. Paper tranſmits but little light; it becomes more tranſparent by ſtopping up its interſtices with oil.

As the parts of bodies muſt thus be cloſe and ſimilar when they are tranſparent, on the other hand, if they reflect light, this muſt neceſſarily come from their pores. The ray, which is attracted by the ſolid parts of the body, is repelled when it comes to a pore; for wherever attraction ceaſes, there repulſion begins. Thus, when the rays of light paſs from air into glaſs, juſt at their entrance into this new medium, ſome of them muſt meet pores, from which they will partly be repelled, and yet a part will enter, and ſo there is a ſmall reflection from the nearer ſurface of the glaſs. As the rays go forward, by coming to the back ſurface of the glaſs, and going again out into air, they will meet with a greater number of pores than they firſt did upon their entrance into the glaſs, and there will be therefore more rays reflected from the back ſurface than from the nearer; and if the rays, inſtead of going out from the back ſurface into air, went into a void, which has ſtill more pores than air, they would meet ſtill more oppoſition to repel their progreſs, and they would be reflected in greater abundance. What is thus true in theory, is equally proved by experience; for if we cover the mouth of a receiver with a glaſs properly diſpoſed, then we ſhall ſee, as the air is pumped from behind, the rays will begin to be reflected from the hinder ſurface in a very copious manner.

IN this manner is light reflected from the pores of all bodies; but it may be objected, that we formerly aſſerted that the denſeſt and thickeſt plates are thoſe which reflect the moſt numerous rays, whereas we now ſay, that the pores reflect the rays only; does not this imply a contradiction? Not at all; for we muſt obſerve that a ray of light is ever moſt reflected when it paſſes between two mediums, which have the greateſt difference in their denſities: for inſtance; it is moſt reflected when it paſſes from a very rare medium, like air, into a very denſe one, like quickſilver. It is repelled from the pores of the latter in great abundance; for quickſilver, though denſe, hath numberleſs pores notwithſtanding.

THIS then brings us to the laſt ſtep of our theory. We ſaid long ſince, that bodies which were very white reflected all manner of rays. Tin is ſuch a body. We now ſay that the denſeſt bodies are moſt apt to reflect rays coming from a rarer medium. Quickſilver has great denſity; a mixture of tin and quickſilver, therefore is made uſe of to reflect the rays in a common mirrour. A tranſparent glaſs plate is fixed before to prevent any injury being offered to ſo ſoft a ſubſtance as the two metals united make; a part of the rays enter the pores of the glaſs, they go through, meet a medium of different denſity, part are reflected from its pores to our eyes, and part go to be loſt irrecoverably in the boſom of the metal.

As the colour, tranſparency, and reflecting power of bodies in this manner ariſe from the different denſities and thickneſſes of the parts of which they are compoſed, it is no way ſurpriſing to ſee two liquors entirely changed by being compounded with each other; for whatever makes a change in the denſity of the parts of which either fluid is compoſed, will of conſequence alter its tranſparency or its colour. If the ſaline parts of one liquor enter the pores of another, this will dilate them, and conſequently alter their colour. If two liquors ferment, the parts of one will be daſhed againſt thoſe of the other, and thus either unite into larger maſſes, and ſo become opake, or break into ſmaller, and thus grow tranſparent. A few inſtances of ſuch alterations in liquids will not be improper.

If we infuſe or ſteep the common gall-nut in water, and mix this with ſome powdered vitriol or copperas, it will make the black liquor, ink. If we pour into this mixture a few drops of aqua-fortis, the whole will then become as clear as water; for there is (if I may ſo ſay) a ſtronger affinity between the vitriol and aqua-fortis, than between the gall-water and vitriol: the vitriol and aqua-fortis therefore attract each other, they unite, and the heavy aqua-fortis drags the vitriol with it to the bottom, leaving the gall-water above all in its former tranſparency. If now ſome drops of a lie of pot-aſh be poured in; as the affinity between the aqua-fortis and pot-aſh is greater than between aqua-fortis and vitriol, the aqua-fortis will deſert the vitriol and cling to the pot-aſh. It drags it down to the bottom, as it before did the vitriol, while in the mean time the vitriol being ſet free, again mixes with the gall-water, and thus the fluid aſſumes its former blackneſs. It may be again made tranſparent, by pouring in a few drops of the ſpirit of vitriol.

A SOLUTION of copper, which is green, is made clear like water by pouring in a few drops of ſpirit of nitre; and by again mixing ſome oil of tartar, it becomes green, as before.

RED roſes ſteeped for a ſhort time in brandy gives a colourleſs liquor. Aqua-fortis, juſt ſlightly dropped in, gives the whole a beautiful red. A lie of pot-aſh turns this to a beautiful green. Spirit of vitriol dropped in, after ſtanding a few minutes, turns the liquor to red.

A TINCTURE of red roſes is made black by a ſolution of vitriol, and becomes red again by oil of tartar.

SOLUTION of verdigreaſe, from a green, by ſpirit of vitriol becomes colourleſs, then by a ſpirit of ſal ammoniac turns a purple, and then by oil of vitriol becomes tranſparent again.

THE following liquors, themſelves void of colour, produce by mixture a highly coloured liquor. Roſated ſpirit of wine, quite limpid, and ſpirit of vitriol, almoſt ſo, produce a red. Solution of mercury and oil of tartar, orange. Solution of ſublimate and lime-water, yellow.

low. Tincture of roſes and oil of tartar, green. Tincture of roſes and ſpirit of urine, a blue. A very ſlight ſolution of copper and ſpirit of ſal ammoniac, purple. Solution of ſublimate and ſpirit of ſal ammoniac, white. Solution of ſaccharum ſaturni and ſolution of vitriol produce a black.

THE following liquors, which are coloured, being mixed, produce colours very different from their own. The yellow tincture of ſaffron, and the red tincture of roſes, when mixed, produce a green. Blue tincture of violets and brown ſpirit of ſulphur united, produce a crimſon. Red tincture of roſes and brown ſpirit of hartſhorn make a blue. Blue tincture of violets and blue ſolution of copper, give a violet colour. Blue tincture of cyanus and blue ſpirit of ſal ammoniac coloured make green. Blue ſolution of Hungarian vitriol and brown lie of pot-aſh make yellow. Blue ſolution of Hungarian vitriol and red tincture of red roſes make a black. Blue tincture of cyanus and green ſolution of copper produce a red.

THESE liquors are moſtly tranſparent, ſo that when a ſquare flaſk is filled with any one of them, with blue ſolution of copper, for inſtance, we can ſee objects through its ſides, all painted, as it would ſeem, with a beautiful blue. But need we by this time obſerve, that if two flaſks of different coloured liquors be placed before the eye, no object whatſoever can be perceived through them? Need we obſerve in this caſe, that the blue rays paſſing through one liquor, will take a different courſe when they come to the other liquor, contained in the adjoining flaſk? The learner knows, without doubt, that the rays will be turned out of their former direction, they will ſuffer a different refraction, and will not give a thorough light through both.

IT only now remains to account for that difference of colour which the ſame object frequently exhibits in different ſituations: thus, the colour of a dove's neck in one poſition is green, and in another, purple. The plumage in a peacock's tail now appears red, then a dazzling green. Some ſilks, looked at directly, are purple, ſidewiſe, they are red. Some liquors, as an infuſion of lignum nephriticum, held between us and the light, ſeems blue, but oppoſite the light ſeems red or yellow. Whence comes this difference? It ariſes from a difference of denſity in the ſmall plates of which thoſe bodies are compoſed. In one poſition, ſome are adapted to reflect the rays, while others to abſorb and tranſmit them; for if we ſuppoſe one of theſe double-coloured objects to be made up of two ſubſtances of very different denſities, for inſtance, the particles of the body itſelf to be one ſubſtance, and the fluid that enters between them another, the reflections from theſe parts of very different denſities muſt be very different at different obliquities of the eye. Let us wet theſe double-coloured objects, let us dip the variegated feather in water, or the changeable ſilk in oil, the denſities and thickneſs of their parts, and the fluid within them are rendered more alike, their reflection will be therefore leſs vivid, and they will return but one uniform ſhade of colouring.

YET perhaps all this may be accounted for on much more obvious principles. The ſmall plates of colour in one poſition are turned to the eye, in another, they are turned away, and a different ſurface preſented to the ſpectator. In the ſame manner in feeling; ſome ſorts of ſtuff, ſuch as common pluſh, if we draw the hand in one direction, will be a ſmooth ſurface, but in an oppoſite direction, very rough. The ſame object may thus preſent different ſurfaces to the eye, as well as the touch; as a field of corn, viewed with the wind, is of a different ſhade from the ſame field viewed againſt the wind; in each caſe, we ſee different parts of the ſame object preſented to the view. The more approaching to the teſtimony of our ſenſes every philoſophical ſolution is, the more perhaps is it conformable to nature. It is the buſineſs of a philoſopher, like a parent, to correct the errors of ſenſe, but not, like a tyrant, totally to reject their information.

CHAP. XI.

Of the Rainbow.

OF all the meteors which reſult from the reflection of light, the rainbow is the moſt pleaſing and extraordinary: its colours not only delight the eye with the mildneſs of their luſtre, but encourage the ſpectator with the proſpect of ſucceeding ſerenity.

IT is but by ſlow and painful ſteps we arrive at the true cauſes of things: the colours of the rainbow, which ſtruck antiquity with amazement, no longer now create the philoſopher's ſurpriſe. To Pliny and Plutarch it appeared as an object which we might admire, but could never explain. The prieſts always preferred the wood on which the rainbow had appeared to reſt, for the burning their ſacrifices, vainly ſuppoſing that this wood had a perfume peculiarly agreeable to their deities. Some philoſophers of the obſcure ages began to form more juſt conceptions concerning this meteor; but Kepler it was, who firſt ſuppoſed that it might ariſe from the refraction of the ſun's rays upon entering the rain-drops. Antonio de Dominis enlarged a theory but juſt hinted at by Kepler; and his treatiſe *De radiis lucis et iride* appeared in the year 1611, ſeveral years after the author himſelf had been driven from his biſhoprick of Spalatro in Dalmatia by the Inquiſition, for attempting to oppoſe the opinions of Ariſtotle, which were then cloſely connected with religion, or at leaſt thought to be ſo. Each ſucceeding philoſopher went on in improving a theory, the truth of which ſeemed to carry great probability. Carteſius and Mariotte both ſet themſelves to improve the inquiry, but as they were ignorant of the true cauſes of colour, they left the taſk unfiniſhed, for Newton to complete. The theory of the rainbow, as explained by him, is full, clear, and impreſſes the mind with perfect conviction. Of all the various meteors which ſerve to terrify or amuſe us, this is the only one, for which naturaliſts can account in a ſatisfactory manner.

IT is needleſs to deſcribe this meteor, which every reader muſt have ſurveyed with wonder. The moſt untutored ſpectator knows, that it is only ſeen when he turns his back to the ſun, and when it rains on the oppoſite ſide. Its colours are, beginning from the under part, violet, indigo, blue, green, yellow, orange, red, ſo that we ſee it contains all the beautiful and ſimple ſhades of the priſm. Without the firſt bow, we often ſee an external rainbow, with colours leſs vivid, and ranged in an oppoſite order, beginning from the under part, red, orange, yellow, green, blue, indigo, violet; ſometimes we ſee half, ſometimes an whole bow, frequently one, very often two, nay, three have been ſeen; Dr. Halley gives an account of his having obſerved ſuch a triple bow at Cheſter, and many others have ſeen the ſame. Now then, to explain the manner in which the bow is made, and the cauſe of theſe various appearances, which it is found to aſſume,

LET us begin this theory with the experiment by which Antonio de Dominis undertook to explain the cauſe of the rainbow: this philoſopher filled a glaſs globe with water, and hung it at a certain height, oppoſite the ſun, then ſtanding himſelf with his back to the ſun and his face to the globe, he found, that when this was placed in ſuch a ſituation, as that a ray darting from the ſun to the globe made angle, with another ray going from his eye to the globe, of forty-two degrees three minutes, in ſuch a caſe, I ſay, he found that the globe appeared red. If the globe was altered, ſo as to make the angle between the ſolar and the viſual ray leſs, then the other colours of the rainbow aroſe, from red down to violet, which appeared at an angle of forty degrees ſeventeen minutes. Let us now ſuppoſe ourſelves in this philoſopher's place, the globe before us, the ſun behind, and its rays againſt the globe making an angle with our viſual ray of forty-two degrees three minutes: we know that millions of the ſun's rays fall upon this globe, and that each ray has a different colour, and is differently refracted upon entering the globe, the red ray being leaſt refracted, and the violet ray moſt of all. For this reaſon, the red rays will paſs out of the globe in one place, the orange rays in another, the yellow, the green, the blue, the indigo, and the violet will all paſs ſeparately. To make this ſtill plainer, let us ſuppoſe this globe an aſſemblage of an infinite number of plain ſurfaces, which it is in effect. (See fig. 80.) Let us ſuppoſe the red rays, A B C to come parallel from the ſun upon three minute ſurfaces of the globe, now we know that each will be refracted or bent in paſſing into the globe proportionally

Pl. 23. p. 392. Vol. II.

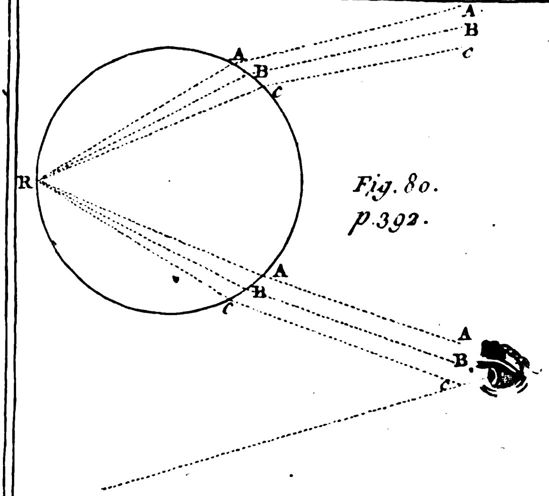
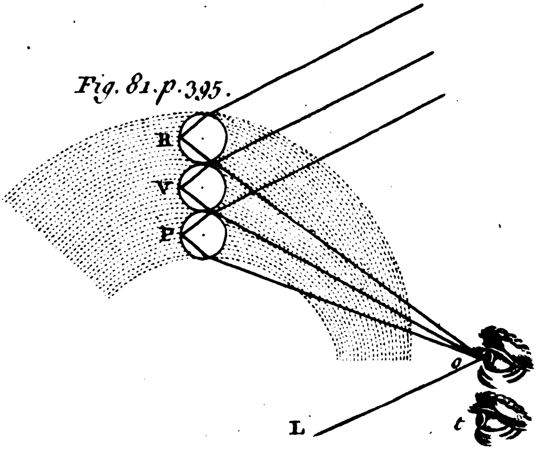


Fig. 80.
p. 392.

Fig. 81. p. 395.



Proud Sculp.

proportionally to its angle of incidence. The red ray A falls with the moſt oblique incidence, and its refraction will be therefore greater than that of the ray B or C, ſo that it will be bent to R. The ray B comes with a leſs oblique incidence, and therefore it will be refracted more directly to the ſame point R; the ray C inciding ſtill leſs obliquely than either, will be leſs refracted, it will go almoſt directly forward to R; thus the three rays, by falling at different angles of incidence, will unite in the ſame place at the oppoſite ſide of the globe. At the point R each ray will be in a great meaſure reflected, making an angle of reflection perfectly equal to the angle of incidence; from R, therefore, each ray will travel backward out of the globe, and upon emerging from thence at *a b c*, they will make the ſame angle with the ſurface of the globe as that by which they firſt entered, they will therefore all turn out parallel as they firſt came from the ſun, and they will ſtrike the ſpectator's eye, if it happens to be placed conveniently, at *o*. If there be a ſufficient quantity of theſe to affect the optic nerve, they will then be ſeen, and appear red. The rays *a b c* are the viſible ones of the globe or drop of water, and every drop of water has thus its viſible rays. There are numberleſs others which do not come to the eye; there are millions of orange, blue, green, violet ones, which ſtriking upon the ſame part of the globe with the red rays, that are differently refracted upon going through, and take a different road upon being reflected back, ſo as not to fall upon the eye placed at *o*. Were the globe lowered a little, and the angle thus made ſmaller, reduced to forty degrees ſeventeen minutes, then the violet rays would ſtrike upon our eye, while the red rays we ſaw before would paſs over our heads, and a ſpectator who looked over us would ſee them.

Now, what has here been ſaid of one globe or drop of water is true of millions of drops. Let us imagine a ſhower falling at ſome diſtance before us, and the ſun from behind us darting its rays upon the numberleſs drops of which it is compoſed. Let us, to avoid confuſion, ſuppoſe we ſee a rainbow of three orders of colours; the drop R, that is ſeen at the largeſt angle, L O R, will be red, the drop ſeen at a ſmaller angle, L O V, will be green, and that ſeen at a ſtill ſmaller angle L O P will be violet. (ſee fig. 81.) Thus, millions of drops will be ſeen of thoſe three different colours: in ſhort, all drops in that ſhower, ſeen at the ſame angles will appear variouſly coloured in that manner: all drops, I ſay again, that are placed between ſuch angles, that is, of forty-two degrees and forty, will be ſeen coloured, and if ſo, we muſt thus ſee part of a beautiful circle of theſe colours; for we may readily ſuppoſe an arch in the heavens, every part of which ſhall be at an angle of between forty and forty-three degrees from the eye, and this arch is the rainbow. Our eye is in the point of a cone, and the rays that dart from it, falling at thoſe angles, form the circular baſe of the cone: a part of this circle we ſee coloured, while the earth cuts off the other part which lies below our horizon.

To make this yet plainer; ſuppoſe the ſpectator were upon the top of a very high mountain, and the drops of rain falling near him, inſtead of a ſemicircular rainbow, he would then actually ſee a complete ring of that beautiful meteor. All drops at an angle of between forty and forty-two degrees will appear to him coloured. One drop may be ſuppoſed to be at that angle above the ſpectator's eye, another at the ſame angle downwards below his eye, one drop at that angle to the right, and another to the left; in ſhort, we may thus complete a circle of drops, and this is that glorious circle which he ſees, a circle not like our common bow, cut off by the earth, but completely beautiful, and uſually ſeen from the American Andes.

Pl.24.p.397. Vol II.

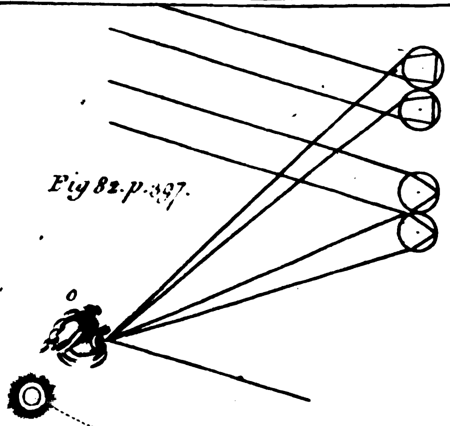


Fig 82.p.397.

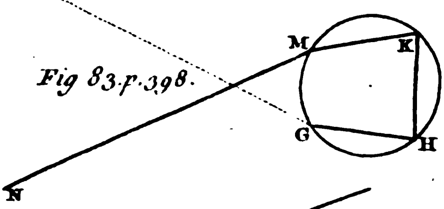


Fig 83.p.398.

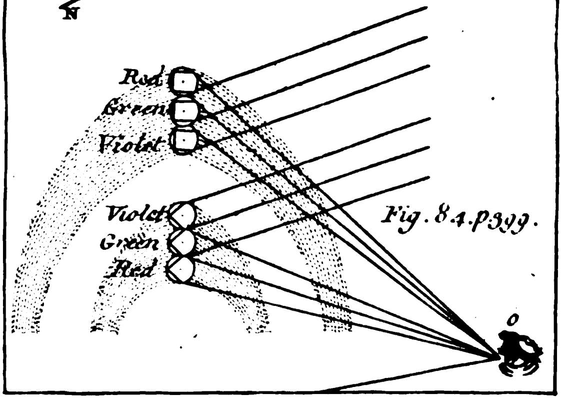


Fig.84.p.399.

Proud Sculp

We come now to the ſecond rainbow, which we obſerved encompaſſed the former, more widely ſpread, more faintly luminous, and with inverted colouring. This bow, like the former, is made by the rays of the ſun darting upon the drops of falling rain, and from thence reflected to the ſpectator's eye. The difference between the two bows is this, that in the internal bow each drop receives the rays of the ſun on its upper ſurface, (ſee fig. 82.) whereas, on the contrary, in the great external bow, each drop receives the ſun's rays at its bottom, from whence the ray being twice refracted and twice reflected, it comes to the ſpectator's eye with diminiſhed luſtre and in an inverted order. But before we explain this, it muſt be obſerved, that as in the former bow experience proved that the drop muſt be placed at angles of between forty and forty-two degrees to tranſmit and reflect the coloured ray, ſo experience likewiſe proves, in the preſent caſe, that the drop muſt be placed at an angle of between fifty degrees fifty-ſeven minutes, and fifty-four degrees ſeven minutes, to appear coloured after two refractions and two reflections, which we ſhall now ſee a ray, paſſing through it, undergoes.

A BUNDLE of rays dart from the ſun on the lower ſurface of the drop at G; (ſee fig. 83.) there a part of theſe enter, while another part is ſtruck back by reflection, and loſt: thus there is already part of the rays ſcattered and loſt to the eye. The part refracted go on to H, a part of theſe go forward into air, and are thus loſt again to the eye, while the little that remains is reflected up to K. Here a third time another part of the ray eſcapes out of the drop, while what remains is refracted to M; at its going out of the drop here, ſtill another part of the ray is ſcattered and loſt, which is a fourth diminution; laſtly, what remains after ſo many diminutions is reflected to the eye at N. Thus the ray comes to the eye after no leſs than two reflections and two refractions; by this means, therefore, it loſes near one half more luſtre than is ſeen in the inner bow, where there is but one reflection only; and the colours alſo of this bow muſt come to the eye in a different order from thoſe of the inner bow; for the eye being placed at O, (ſee fig. 84.) it receives the leaſt refracted red rays from the outer edge of the internal bow, and it muſt therefore receive the moſt refracted or violet rays from the inner edge of the external bow, the violet ray *b* being much more refracted than the red ray *a*, as we ſee by the figure.

SUCH is the nature of this meteor formed by the ſolar rays; but there is ſometimes alſo a lunar rainbow, formed exactly in the ſame manner, by the bright beams of the moon ſtriking upon the boſom of a ſhower. This meteor Ariſtotle boaſts himſelf to have firſt remarked, and aſſures us, that in his time ſuch a rainbow was ſeen, with the colours extremely lucid. Similar meteors have been frequently obſerved ſince his time; and, among our own countrymen, Mr. Thoreſby has given the deſcription of one in the Philoſophical Tranſactions. The lunar rainbow which he obſerved was equally admirable both for the beauty and the ſplendor of its colours: it laſted ten minutes, till at length a cloud came and intercepted the view.

BUT we muſt take eſpecial care not to confound this appearance cauſed by the moon, with that lucid ring which we often ſee diffuſed round it, called an Halo, for the production of which philoſophy has as yet found no probable ſolution. Huygens ſuppoſes that there are certain globules in the atmoſphere, conſiſting of a tranſparent ſhell of ice or water, but perfectly opake within; and that from the partial reflections of theſe ariſes this meteor. This can give us but very little ſatisfaction in our reſearch. An infinite number of drops with icy coats and opake kernels is a greater wonder than the Halo itſelf; we muſt therefore leave this meteor, with ſome others, ſuch as the Parhelia, or mock-ſuns, the Paraſelenae, or mock-moons, which ſo often appear in the regions round the north pole, quite unaccounted for. No illuſtrations are better than falſe illuſtrations. The rainbow is the only meteor for which we can clearly account; and it is thus, that while philoſophy excites man's pride on one hand, it generally ſerves to mortify his preſumption on another.

CHAP. XII.

Of adventitious Colours.

WE have hitherto conſidered colour as it is in the light, and as every object is peculiarly adapted for ſeparating its different rays: we muſt now obſerve, that there are often colours in the eye itſelf, which alter the tints of objects contrary to our deſire; we often ſee things peculiarly tinctured, when we know their colour to be different from what it appears. To a jaundiced perſon, white objects ſeem yellow; for the humours of his eye are then actually tinged with that colour. To a perſon in a fever, the ſame objects appear red, from ſome ſimilar alteration: thus, a change in the organ ever makes a ſeeming change in the object, ſo that we may now aſſert, that the colour is properly neither in the object, nor in the colouring ray, but in the mind, which perceives either. If the eyes of all men were naturally jaundiced, all white objects would appear uniformly yellow.

A QUESTION of a very intricate nature now therefore ariſes. Do all men ſee the ſame objects of the ſame colour? Do thoſe fields which ſtrike me with an idea of green, preſent a ſimilar green to the friend with whom I am walking? we both, it is true, conſpire to call that beautiful verdure by one name, yet may it not affect him with the ſame ſenſation which I receive from red, or any other colour? To make this plainer, ſuppoſe his eye were jaundiced from the birth, then it is evident that green would appear to him yellow; yet though we are ſure he ſaw the colour wrong, yet this would cauſe no error either in his own ideas, or his converſation; for he would ſtill continue to call that yellow colour green, and we ſhould underſtand him very readily. If a great part of mankind had their eyes thus tinctured, each would ſee objects different from his fellow, yet none would be ſenſible of the miſtake. I ſay then again, May not different men have different ideas of the ſame colour? I am apt to think their ideas are different. If two men look at the ſame ſhining ſpot of red upon a white wall for ſome time ſteadily, the colour will ſeem to alter to each, and new colours will ariſe. Theſe adventitious colours, however, which the ſpot ſeems to aſſume, are different to different perſons: the ſpot turns to blue in my eye, while it becomes green to the eye of another ſpectator that obſerves it with me. Now, if we had both originally ſeen the red ſpot of the ſame colour, we ſhould ſee the changes it underwent of the ſame colour alſo; for if two things are exactly alike, ſimilar operations upon them will produce ſimilar effects. But in the preſent caſe, two different effects, two different colours are produced to each ſpectator from obſerving the ſame object, a proof that the cauſe which produced this difference muſt alſo be double, or that the red ſpot excited two different ideas originally.

However this be, the theory of adventitious colours, or colours which ariſe when the organ is intenſely exerted, is a new and a pleaſing ſubject: it was firſt ſtarted by Dr. Jurin, whom more than once we have had occaſion to mention with reſpect. It was purſued by Monſ. Buffon, and he has given the hiſtory of his particular ſenſations in this purſuit very accurately; every ſpectator may readily compare them with his own, and thus diſcover how far his organs of viſion reſemble thoſe of others. I have tried the experiment with regard to myſelf, and have found the colours change to my view in a very different order from that in which they appeared to the French naturaliſt; the changes as ſeen by him are thus related:

When a red ſpot upon a white ground is earneſtly regarded for ſome time, a kind of green bordering is obſerved round the ſpot, and if the eye be taken off from the ſpot, and thrown upon another part of the wall or ground, it ſtill continues to ſee a green bordering as before, approaching a little towards blue.

IF, ſays he, we obſerve fixedly and for a long time a yellow ſpot upon a white ground, we ſee the ſpot at length begin to be bordered with a pale blue, and if we avert our eyes towards another part of the white ground, we ſhall diſtinctly ſee a blue ſpot of the ſize and figure of the yellow one obſerved before.

IF we obſerve ſtedfaſtly and for a long time a green ſpot upon a white ground, we ſhall ſee a bordering of lightiſh purple, and in averting the eye, we ſhall ſee a purple ſpot of the dimenſions of the former.

IF we obſerve in the ſame manner a blue ſpot upon the ſame ground, we ſhall ſee a bordering of white inclining to redneſs,

neſs, and averting our eyes, we ſhall ſee a ſpot of a light red.

If we obſerve attentively a black ſpot upon a white ground, we ſhall ſee a bordering of bright white, and turning to another part of the wall, we ſhall ſee a ſpot of exactly the ſame dimenſions with the former of a whiteneſs far exceeding that of the wall.

If we obſerve long and attentively a ſquare ſpot of bright red upon a white ground, we ſhall firſt begin to ſee the ſlight green bordering mentioned above; continuing to look with fixed attention, we ſhall ſee the middle of the ſquare begin to be diſcoloured, and the ſides aſſume a deeper red, and forming a ſquare of a dark crimſon; then retiring a little backwards, ſtill keeping our eye fixed, we ſhall ſee the crimſon edge or ſquare croſs the ſpot, and appear in the manner of a ſaſh-window with four panes of glaſs, the croſs bars in this little ſquare being as viſibly different as the wood from the glaſs in the window; continuing ſtill to look ſtedfaſtly and with perſeverance, this croſs changes again, and we ſee only a right angle of a red, ſo ſtrong and penetrating, that it entirely dazzles the eye, and the organ becomes incapable of bearing further fatigue. If now the eye be turned upon another part of the white wall, the right angle will ſtill appear, but no longer red, but of a bright and luminous green. This impreſſion remains a long time, its colours fade away ſlowly, and even remain after the eye is ſhut.

WHAT thus is effected by regarding the red ſpot, will alſo be the conſequence of our regarding a yellow, a green, a blue, or black ſpot, the croſs and the right angle will ſucceſſively appear each of a colour which is peculiarly adventitious to itſelf.

AFTER looking at the ſun as long as the eye could bear, the image of this luminary was ſo ſtrongly imprinted, that it mixed itſelf with every object that was viewed for ſome time after, in a manner reſembling what has been already related.

SUCH is the hiſtory of Monſ. Buffon. It now remains to be obſerved, that in whatever manner it may in general deſcribe the ſenſations of ſome eyes, it certainly does not agree with the changes which are wrought in all. The experiment is eaſy; and every ſpectator may be ſoon convinced, that the adventitious colours here deſcribed will not be exactly ſimilar to thoſe deduced from his own experience. What then can we gather from this inquiry? Only this, That colour is in the organ, not in the body ſeen: that man often makes colours without an object: that adventitious colours are not the ſame to every eye; and as theſe ariſe different, ſo it is very probable that the original colours, which are the ſources from whence the others proceed, are alſo different: in other words, that the ſenſations which different men have from the ſame coloured object are as much diverſified as the organs that view them; and that not the things but the names are all that we can argue upon with certainty.

IT is a concluſion ſufficient to mortify reaſoning pride, that the more minutely we penetrate into nature, the more we find cauſe to diſtruſt our guide itſelf: that the deeper ſcience is purſued, the more it ſerves to diſenchant thoſe pleaſing deluſions which itſelf had before taught us to fancy. A minute inveſtigation of nature ſtill preſents new wonders, till at laſt, the philoſopher ſeeing the number riſe upon him on every ſide, each equally amazing and equally inſcrutable, he at length loſes curioſity in deſpair, and wonders at nothing: yet let us while we live ſtrive to be amuſed and to amuſe each other. If our happineſs hereafter is to conſiſt in knowing much, let us here, by our feeble anticipation at leaſt, ſhew a paſſion for the enjoyment of ſcientific felicity.

FINIS.